GAGES, GAGING AND INSPECTION

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GAGES, GAGING AND INSPECTION

A COMPREHENSIVE TREATISE COVERING THE LIMIT SYSTEM, MEASURING MACHINES, AND MEASURING TOOLS AND GAGES FOR ORIGINATING AND COMPARING MEASUREMENTS IN THE MANUFACTURING AND INSPECTION DEPARTMENTS, INCLUDING MEANS FOR MEASURING AND INSPECTING SCREW THREADS AND GEARS

BY

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PREFACE

THE development of interchangeable manufacture has made necessary a complete revolution in the gaging and inspection systems employed in the mechanical industries. The introduction of the limit system in manufacturing has changed many of the methods previously in vogue. The intensive manufacture of arms and ammunition during the past few years has also more than ever indicated the necessity of accurate and reliable means of gaging and inspection. No book has been published in the past dealing exclusively with this subject, nor dealing comprehensively enough with it to meet the requirements at the present time, and for this reason the present volume has been prepared with a view to cover the principles and the practical application of the limit system of interchangeable manufacturing, and to describe the principal tools and gages that are employed in this work in leading manufacturing establishments in the country.

The principles of the limit system are first dealt with, and then the different kinds of measuring machines and reference and working gages are illustrated and described. Gages of many different types are included — plug and ring gages, profile gages, indicating gages, thread gages, and devices for measuring gears of different kinds. The book should, therefore, appeal to those responsible for the output of shops manufacturing on the interchangeable plan, inspectors, foremen, designers of special measuring tools, toolmakers, and others whose duties are in one way or another connected with the problems of interchangeable manufacture, the gages used, and the inspection methods required.

THE AUTHOR.

NEW YORK, *February*, 1918.

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GAGES, GAGING AND INSPECTION

CHAPTER I

REFERENCE STANDARDS AND MEASURING MACHINES

In measuring work, many different appliances are used, the kind of measuring tool depending upon the accuracy required. For instance, in ordinary machine work, the bow caliper and scale are used to a large extent for making diameter and length measurements. When the work calls for a greater refinement, the micrometer caliper, vernier caliper, micrometer depth gage, etc., are applied. When still greater accuracy is demanded, measuring machines are used. For angular measurements, squares, bevel protractors, and templets are employed.

Standard Unit of Length. — The international meter is the fundamental unit of length in the United States. The original standard is retained by the International Bureau of Weights and Measures, near Paris, France. Several copies of this primary standard were made in 1889 for the United States and other governments under the direction of the International Committee representing the various countries which support the bureau. The Bureau of Standards, Washington, D. C., has two copies of the original meter; one — No. 27 — is kept sealed in a metal case in a fireproof vault, and the other — No. 21 — is used occasionally to verify the working standards. The legal equivalent of the meter for commercial purposes was fixed by law, in 1866, as 39.37 inches. The United States Bureau of Standards was authorized by executive order, in 1893, to derive the yard from the meter by the use of this relation. Metric length measures tested by this bureau are standardized at 20 degrees C., and standards in the customary

units of yards, feet, and inches are made to be correct at 62 degrees F.

Reference Standards. — In order to check various measuring instruments, micrometer calipers, standard and special gages, etc., different types of reference rods and blocks have been devised. These are very carefully seasoned and lapped, and are usually supplied in sets varying from blocks of the thickness of feelers to rods several feet in length. Fig. 1 shows several types of reference blocks, disks, and rods. The block shown at *A* is made from steel, hardened and ground, with

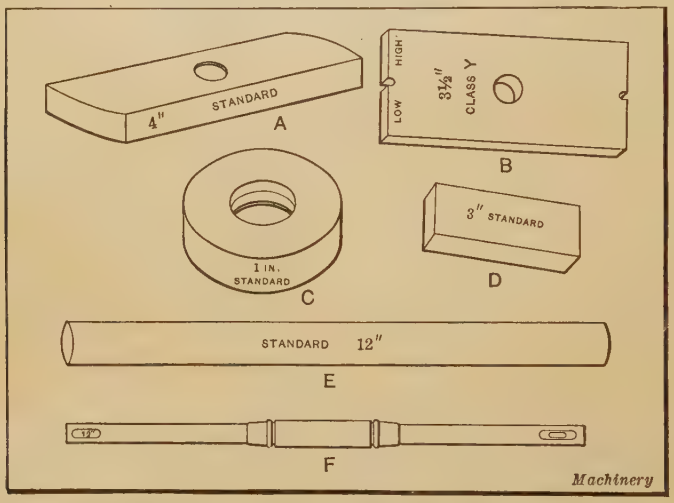

Fig. 1. Standard Reference Blocks, Disks, and End-measuring Rods

cylindrical ends, and is used for setting micrometers and other adjustable measuring tools; *B* shows another type of block which is particularly adapted for setting the adjustable points of limit gages. A disk type of standard which is used principally for setting micrometer calipers is shown at *C*, while a standard block used both for setting gages and for general tool-room purposes is shown at *D*. At *E* is shown a standard end-measuring rod which is made with rounded ends having a radius equal to that which the rod is intended to measure. These rods are made $\frac{3}{8}$ inch in diameter for lengths of from 3

to 6 inches, and $\frac{1}{2}$ inch in diameter for lengths of from 6 to 16 inches. At *F* is shown another type of standard reference rod which is made from round steel rods, hardened, ground and lapped on the ends. To prevent expansion due to handling when in use, the center portion of the rod is fitted with a sleeve of heat-insulating material.

Johansson Reference Blocks. — The Johansson system of reference blocks was originally designed to be used in the tool-room for quickly laying out and checking gages and fixtures. Owing to the extreme accuracy to which these blocks are made, however, they are also used as reference gages, both for manu-

Fig. 2. Johansson Reference Blocks

facturing and for inspection purposes. Fig. 2 shows one set of these blocks. The combination consists of a series of rectangular blocks, which are made from nickel steel, carefully machined, seasoned, ground and lapped on all sides. The opposite sides of each block are parallel, and the distance between them is equal to the dimension stamped on them within a maximum tolerance of 0.00001 inch per inch. These blocks are supplied in various sets, set No. 1, shown in Fig. 2, comprising eighty-one blocks, divided into four series. The first series contains nine blocks, which vary in thickness from 0.1001 to 0.1009 inch, increasing by 0.0001 inch increments. The second series contains forty-nine blocks, which vary in thick-

ness from 0.101 to 0.149 inch, increasing by 0.001 inch. The third series comprises nineteen blocks, varying in thickness from 0.050 to 0.950 inch, increasing by 0.050 inch increments; and the fourth series consists of four blocks of 1, 2, 3, and 4 inches. This set gives all the sizes from 0.200 inch up to 11 inches by increments of 0.0001 inch. When furnished with standard plugs and holder for retaining these blocks, over 100,000 different internal and external gages are obtained. The range can be increased by adding other series of blocks up to 20 inches, and increments in quarter thousandths can be obtained by adding two blocks, 0.10025 and 0.10075 inch.

These blocks are generally used by building them up to obtain the required size, and owing to the almost perfect flatness of the surfaces, they can be wrung together with sufficient pressure so that the total number in the set (eighty-one) can be built up. The contacting surfaces are carefully cleaned with chamois skin, and then the gages are slid over each other with a slight pressure. To illustrate how these blocks are used in combination to obtain any desired size, assume that it is necessary to measure 3.3625 inches. This can be done by using four blocks: 3.000, 0.140, 0.122, and 0.1005 inch. Other combinations can also be used for the size given. These blocks can also be extensively used for setting and checking limit gages. With the set of eighty-one blocks, any limit gage having a tolerance as small as 0.0001 inch, from 0.200 inch up to over 11 inches, can be checked.

Bench Micrometer Caliper. — One of the simplest types of measuring instruments which comprises the principle of the micrometer screw and graduated sleeve is shown in Fig. 3. This is known as a " bench micrometer caliper " and is used on the bench for taking fine measurements from 0 to 6 inches. It is provided with two interchangeable measuring heads, the one shown on the instrument being graduated to read to 0.0001 inch directly from the thimble, and the other shown at *A* being provided with a ten-pitch screw and graduated to read to 0.001 inch. The thimbles are 4 inches in diameter, and consequently have coarse graduations, enabling accurate readings to be

quickly taken. The adjustable anvil is set by standard reference blocks. The screw on the thimble has a movement of 1 inch.

Principle of Measuring Machines. — Measuring machines generally comprise both a vernier scale and a micrometer screw and wheel. Usually the vernier scale is attached to the bed of the instrument and is used for setting the headstock bracket carrying one anvil; the headstock also carries the graduated wheel operating the spindle through a screw. There are three important points to consider in designing a measuring machine: First, to produce an accurate screw, vernier, and wheel; second,

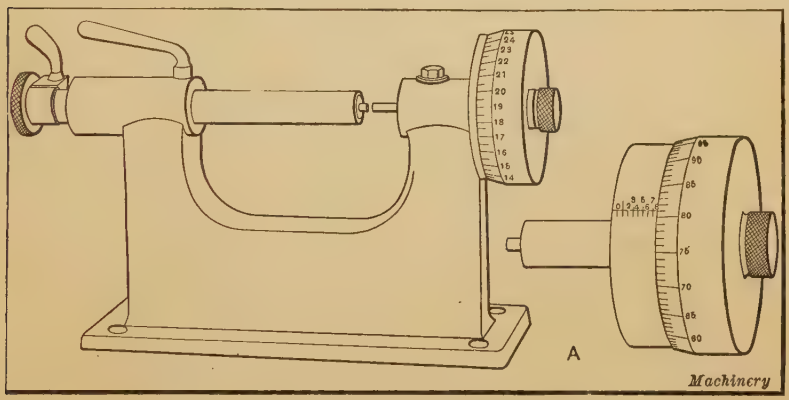

Fig. 3. Bench Type of Measuring Machine

to secure the proper proportions and rigidity of the bed; and third, to provide some means of indicating the pressure exerted on the work placed between the measuring points.

While all three points are highly important, the third one is probably the most important and the one that should receive the most careful attention. A measuring machine not provided with a pressure indicating device is only of value in the hands of an expert, and it is practically impossible for two men to obtain exactly the same readings. Pressure indicating devices are made in several forms, such as feeler plugs which drop out from between points when a certain pressure is reached; levels which are inclined at an angle when acted upon by the moving

anvil; spring-operated plungers, in conjunction with a scale and hair-line microscope; and graduated glass tubes into which a colored liquid is forced by the pressure of a diaphragm connected to the movable anvil.

Brown & Sharpe Measuring Machine. — The measuring machine designed and used by the Brown & Sharpe Mfg. Co. for testing the accuracy of standard gages and other tools that must be finished to very accurate dimensions is shown in Fig. 4. This machine belongs to that class of measuring instruments in which the measurement is made by means of a moving scale under a microscope, used in conjunction with a micrometer

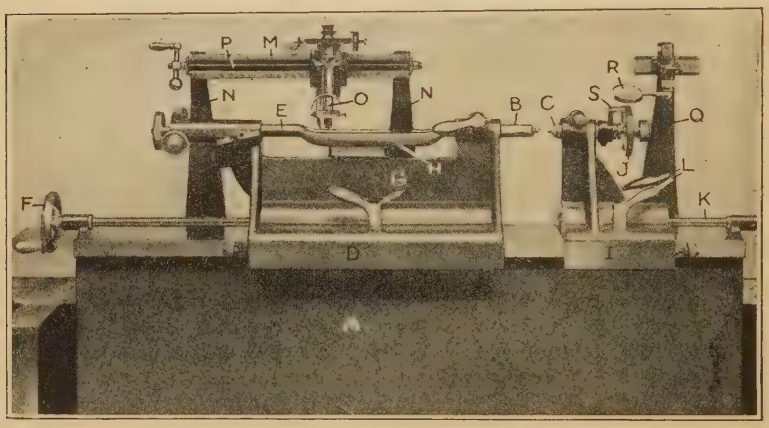

Fig. 4. Brown & Sharpe Measuring Machine

screw and vernier. The most important feature of this machine is that all measurements are made directly from the scales, and dependence is not placed upon standard test pieces that have been previously measured by other means.

This measuring instrument consists of a heavy bed *A* made of double I-beam section about 4 feet long and $1\frac{1}{2}$ foot deep. The I-beam section combined with the weight of the bed gives the machine great rigidity to resist any tendency to deflect when the anvils or measuring points *B* and *C* are brought into contact with the piece to be measured. The carriage *D* on the left-hand side of the bed supports bar *E* which carries the

graduated scale. This carriage is moved by adjusting screw *F*, and clamped by handle *G*. Bar *E* is provided with coarse and fine graduations, and its central portion, which carries the graduated scale, is cut away, thus placing the scale in a line with the axis of the measuring points. The guide *H* which fits in a slot in the lower surface of the bar holds it rigidly in position. The carriage *I* on the right-hand end of the machine supports the micrometer adjustment *J*. This carriage is regulated by an adjusting screw *K* and clamped by handles *L*. Measuring points *B* and *C* are integral parts of the cylindrical bar and micrometer screw, respectively. The slide *M*, supported parallel to the bar *E* by the uprights *N*, carries the microscope *O*. Screw *P* is used to adjust the microscope along the slide. Upright *Q* holds the reading magnifying glass *R* that facilitates taking readings on the micrometer vernier.

The scale on the bar *E* is 8 inches long and is attached to a flat surface. It has two lines of graduations, each division being 0.025 inch. One line of graduations, which is easily visible to the naked eye, is used for locating the scale approximately. The other graduations, which are invisible to the naked eye except under favorable light conditions, are used for the exact reading of the scale by means of the microscope *O*. The lines of these graduations are 0.0001 inch wide, being the same width as the hair line of the microscope; thus the two lines can easily be brought to coincide. The machine can be set to measure distances up to 16 inches long.

The micrometer wheel *J* is graduated to read to 0.0001 inch, and the vernier plate *S* used in connection with the wheel makes it possible to obtain readings as fine as 0.00001 inch. The wear of the micrometer screw is negligible, inasmuch as the micrometer readings are only used for short distances and the wheel never moves more than half a turn. The accuracy of this screw is also greatly increased by providing it with a bearing practically equal to its length.

Method of taking Measurements. — To measure an object, slide *D* carrying bar *E* is moved to the right so that the measuring point *B* will touch the micrometer point *C*. The micro-

scope *O* is then set over one line of the scale, generally the zero line, and the slide is moved to the left until the nearest graduation of the required size is reached. This is indicated by bringing the line of the scale under the hair line of the microscope. The slide is then fastened by clamping handle *G*. Readings less than 0.025 inch are indicated by the micrometer screw and dial *J*. The object to be measured is inserted between the measuring points *B* and *C*, and by adjusting the micrometer screw, the size can be indicated to 0.00001 inch.

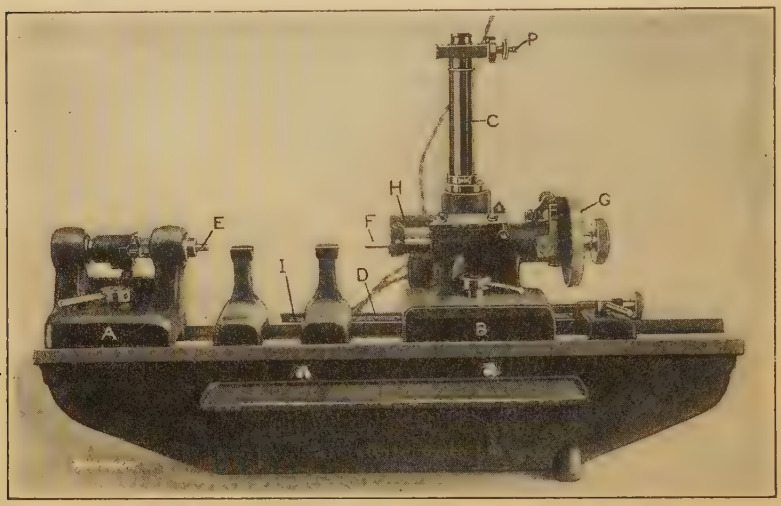

Fig. 5. Pratt & Whitney Measuring Machine

The accuracy of this machine rests fundamentally upon the accurate graduations on the scale and the perfection of the micrometer screw. Among other factors that contribute to the accuracy of the machine are the weight of the bed and the rigidity of the carriages that support the measuring instruments. All bearings and wearing surfaces are scraped accurately to reduce any possible error. The machine is also firmly braced. As an example of the accuracy of this machine, it might be mentioned that a pull of about from fifty to seventy-five pounds on the bed directly beneath the measuring points is sufficient to make a plug $\frac{1}{4}$ inch in diameter drop out from

between the measuring points. Another test which shows the sensitiveness of the machine consists in placing the hand on the bed between the slides and holding it there for approximately one minute; the heat of the hand causes the plug to drop from the measuring points. It is estimated that it requires about twenty minutes for the machine to regain its "equilibrium" and overcome the influences exerted by the pull or temperature test.

Pratt & Whitney Measuring Machine. — The Pratt & Whitney measuring machine shown in Fig. 5 employs what is known

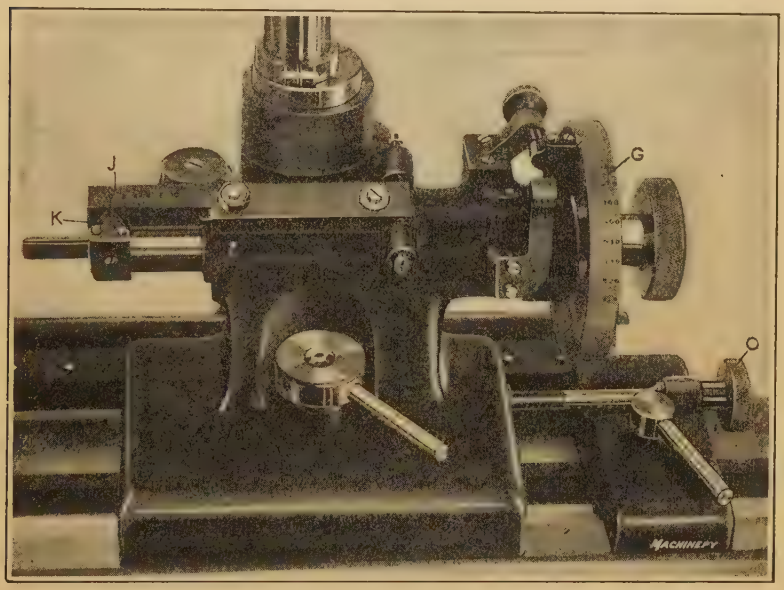

Fig. 6. Close View of Pratt & Whitney Measuring Machine, showing Graduated Wheel and Vernier Scale

as a "feeler plug" for determining the pressure between the measuring points, thus eliminating the human element. This machine consists of a heavy cast-iron bed provided with ways upon which two heads are mounted. One head *A* is normally fixed to the bed; the other head *B* is adjustable and is located along the bed by means of a microscope *C* and measuring points *D*, consisting of plugs provided with fine lines that are spaced exactly one inch apart. Each head carries a spindle or meas-

uring point E and F, and the parts to be measured are supported between these spindles upon rests, or held in the hand, if very small. Measurements up to one inch are obtained by means of a large graduated index wheel G, a scale and pointer at H being provided for approximate setting. This is more clearly shown in Fig. 6; scale J has twenty-five graduations representing a movement of the spindle of 1.000 inch, and pointer K has a single setting line. For measurements greater than one inch, the sliding head B is set by means of a standard bar I located at the rear of the machine. This bar carries a series of plugs D which are provided with graduations exactly one inch apart and so fine that they are imperceptible to the

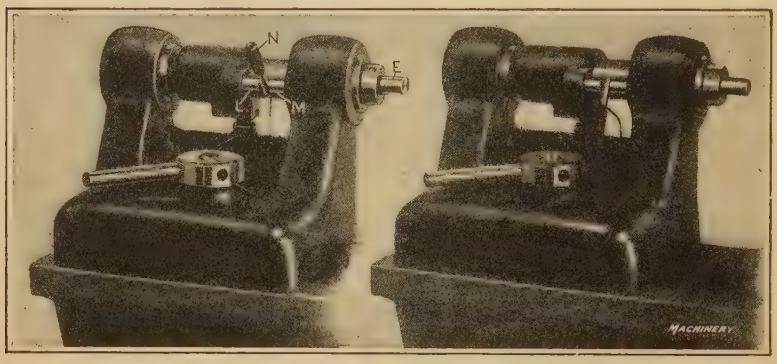

Fig. 7. Close Views of Pratt & Whitney Measuring Machine, showing Position of Feeler Plug before and after taking a Measurement

naked eye. The screw of the sliding-head spindle, by means of which the adjustments for fractional parts of an inch are obtained, has twenty-five threads per inch, and the index wheel has 400 graduations. Therefore, each graduation represents $\frac{1}{400}$ of $\frac{1}{25}$ inch, or 0.0001 inch. These divisions can be split up by estimating, making possible the reading of accurate measurements to 0.00002 inch with little difficulty.

In order to insure proper contact between the measuring points of the instrument, the machine is provided with an indicating device on the fixed head A. This consists, as shown in Fig. 7, of two auxiliary jaws L and M, between which a small $\frac{1}{4}$-inch diameter plug N is held by the pressure of a light

helical spring which operates the sliding spindle to which one of the jaws is attached. The tension of this spring is so adjusted that, when the measuring points are not in contact, the jaws will hold the plug *N* by friction in the position shown to the left in Fig. 7. When the measuring points are in contact with one another or with the work being measured, the tension on this helical spring is slightly reduced, and the plug *N* swings down to a position between the jaws, as shown to the right of the illustration. Should there be an excess pressure between the jaws, the plug would drop out. Hence, the contact for all measurements should be just enough to cause plug *N* to swing down, but not to drop out. It is estimated that the measurable difference between the faces of the measuring spindles when the feeler plug is in the upper and lower positions is $\frac{1}{250,000}$ inch.

In taking a measurement, the machine should first be set to the zero position with the measuring points in contact. This is done by adjusting the screw of the linear scale at the top of the head to zero and setting the pointer of the index wheel *G* nearly to zero. Then the head is slid along the bed until the measuring faces are almost in contact. For the last adjustment, screw *O*, Fig. 6, is operated until the feeler plug *N*, Fig. 7, shows a tendency to move to the horizontal position. The head is now clamped firmly in position and the index wheel adjusted until the plug swings to a vertical position. Then the adjustable index pointer is set to zero and the line in the eye-piece of the microscope is set so that it exactly coincides with the zero line of the graduated reference bar *I* at the rear of the machine. The adjustment of the line in the eye-piece is made by means of the screw *P*. The machine is now set to the zero position, and, when adjusting the head for the required measurement, care must be taken not to disturb the eye-piece of the microscope. To measure from zero to one inch, the micrometer screw can be used directly, but, for a greater dimension, the sliding head must be located by means of the microscope so that the line in the microscope is set exactly on the nearest graduation on the plugs on bar *I*.

Assuming that it is necessary to take a measurement of 12.2508 inches, slide the movable head *B* along the bed until the microscope is brought directly in line with the 12-inch graduation on bar *I*. The screw is now turned back until the scale and index wheel of the adjustable spindle show a movement of 0.2508 inch. As the pitch of the screw is $\frac{1}{25}$ inch, a complete turn of the index wheel equals 0.040 inch. Hence, for a movement of 0.2508 inch, the number of turns of the index wheel would be six full turns and 108 divisions. The Pratt & Whitney measuring machines are graduated for English measurements at 62 degrees F., and in sizes of from 12 to 144 inches.

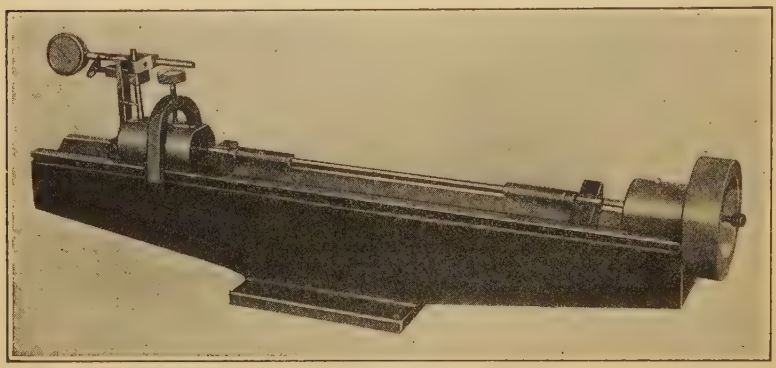

Fig. 8. Slocomb Measuring Machine

Slocomb Measuring Machine. — The type of measuring machine used by the J. T. Slocomb Co. is shown in Fig. 8. This machine is of comparatively simple construction, and consists of a bed carrying two heads. The heads are of circular section and slide in a V-groove in the bed, and when set in the required position are clamped by a C-clamp, as shown. This machine is used principally for duplicating measurements by using master end-measuring rods for setting. The screw has 40 threads per inch, and the dial is 5 inches in diameter and reads to 0.0001 inch.

The most interesting part of this measuring machine is the device for indicating the pressure exerted between the measuring points. When taking measurements to 0.0001 inch with

an ordinary micrometer, it is difficult to determine just what pressure is being applied on the work; and two inspectors seldom obtain the same reading. This pressure indicating device, which is shown in detail in Fig. 9, eliminates the human factor in taking accurate measurements. In Fig. 9, *A* represents a section through the tailstock to which the device is attached, and *B* is the plunger anvil which is retained in bushings. This anvil is made a nice sliding fit in the bushings, and is kept against the front bushing by means of the spring *C*. The movement of the anvil is limited by means of the pin

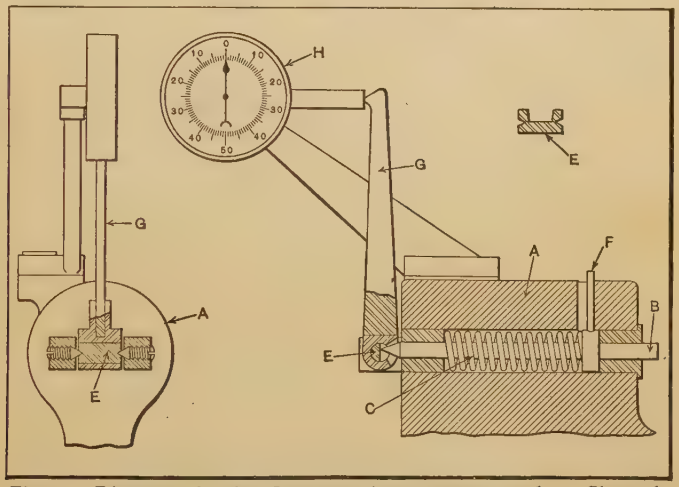

Fig. 9. Diagram showing Pressure Arrangement used on Slocomb Measuring Machine shown in Fig. 8

F driven into the collar and working in an elongated slot in the tailstock *A*. The rear end of the anvil *B* is pointed to an angle of 60 degrees and rests against a flat portion on pin *E* which is retained in the lower end of lever *G*. Pin *E* is fulcrumed on two cone-pointed screws, as shown in the view to the left, and its axis is located $\frac{1}{16}$ inch below the point of the plunger. The ratio between the short and long arms of the lever is $\frac{1}{16}$ to 4 inches, so that, when anvil *B* moves 0.0001 inch, the top part of lever *G* moves 0.0064 inch. The top part of lever *G* bears against the plunger of the dial indicator *H*, and the indicator hand moves about $\frac{3}{8}$ inch when the plunger or

anvil *B* is moved 0.0001 inch. A test made in connection with this instrument showed that the heat from three fingers of the hand applied for a few seconds to a 4-inch end-measuring rod, $\frac{5}{16}$ inch in diameter, was sufficient to move the hand of the dial indicator $\frac{1}{4}$ inch. In testing two pieces with this instrument, the needle will stand at zero when they are of the same length. If the needle moves from zero, it indicates that there is a variation between the lengths of the two pieces.

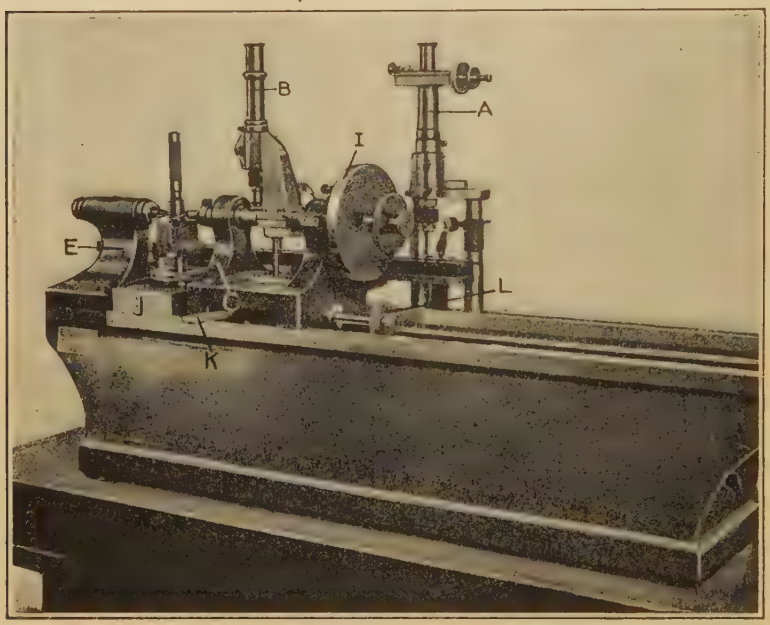

Fig. 10. Swiss Type of Measuring Machine

Swiss Measuring Machine. — A measuring machine which differs somewhat in principle from those previously described is shown in Figs. 10 and 11. This machine is built by the Societé Genevoisé, Geneva, Switzerland. It is provided with two hair-line microscopes *A* and *B*. Microscope *A* is used for setting movable head *C* when taking measurements of over twenty-five millimeters. This microscope is provided with cross-hairs which are brought in line with the graduated marks on a scale located at the rear of the instrument. This scale

is 510 millimeters long and is graduated in millimeters. Microscope *B* is used for determining the position of spring plunger *D*, which governs the pressure exerted on the work. Head *E* is fastened rigidly to the base and carries the stationary anvil *F*, which can be adjusted in case of wear. Spindle *D* is held in a sleeve *H*, the movement of which is controlled by a screw of $\frac{1}{2}$-millimeter pitch, and which is attached to the graduated wheel *I*. Located behind spindle *D* is a light spring capable of exerting a pressure on the work of one pound per square inch.

In setting the machine for measurements of more than twenty-five millimeters, head *C* is slid along the bed until both anvils

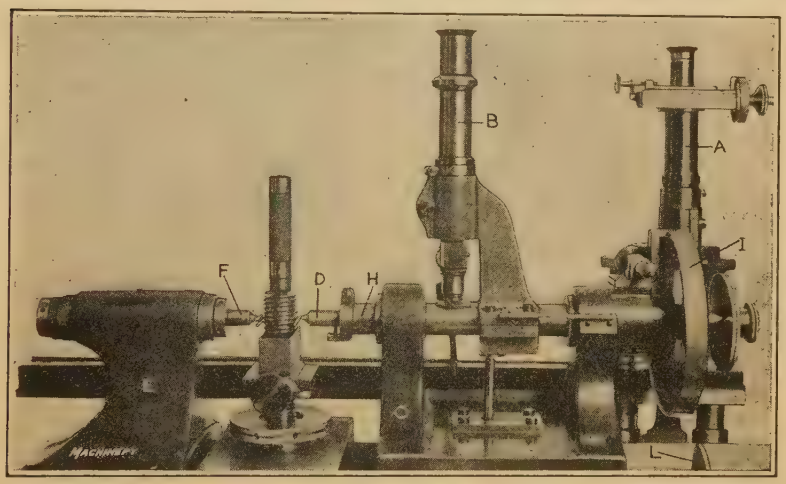

Fig. 11. Close View of Machine in Fig. 10 showing Graduated Wheel and Vernier Scale

contact with sufficient pressure so that the line on the sliding spindle is exactly central between the two cross-hairs in microscope *B*, the graduated wheel *I* at the same time being set at zero. The head is now moved back to approximately the distance required, using the coarsely graduated brass scale at the rear, and is clamped by handle *K*, Fig. 10. Screw *L* is then adjusted until the cross-hairs in the telescope *A* exactly coincide with the required graduation on the scale at the rear. The machine is now set to the dimension required. To deter-

mine the accuracy of the piece being measured, it is located between the measuring points and the position of the line in the movable spindle noted; if this is not exactly in the center of the two cross-hairs in telescope *B*, wheel *I*, which is divided into 500 parts giving direct readings to 0.001 millimeter, is rotated until the line is directly in the center of the two hair lines. The amount that wheel *I* has been moved away from the zero point indicates the amount that the part varies from the required size in thousandths of a millimeter.

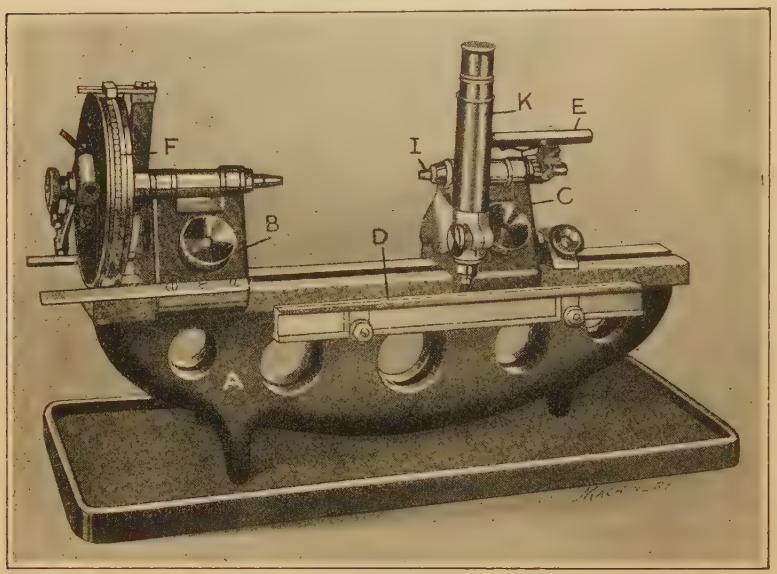

Fig. 12. Newall Measuring Machine

Newall Measuring Machine. — The measuring machine built by the Newall Engineering Co. of Walthamstow, London, England, is suited for general employment in tool-rooms and workshops. It permits of making very fine measurements, and is simple in operation. The features of the machine eliminate errors in measuring, and it maintains its accuracy and requires only slight attention for adjustment. As shown in Fig. 12, it consists of a rigidly ribbed bed *A* on which two slides *B* and *C* are mounted. Attached to the bed is a vernier scale *D*,

providing for the approximate setting of slide *C*. Slide *C* carries the tail measuring spindle *I* and a telescope for setting the position of the slide. In addition, as shown in Fig. 13, it carries an indicating spirit level *E*, which is one of the most interesting features of the machine. When pressure is applied to the measuring anvil through the piece being measured, this spirit level is tilted out of the horizontal plane, due to the backward movement of the anvil; the curvature of the vial gives a movement to the bubble four thousand times the movement of the anvil. This device is so sensitive that the slightest expansion or contraction of the piece being measured, due to

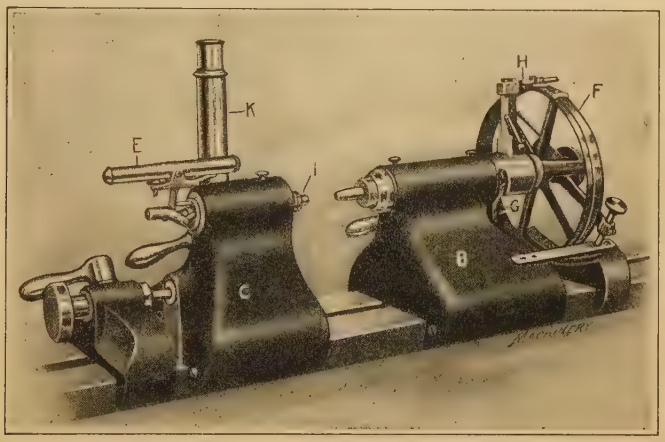

Fig. 13. Close View of Newall Machine showing Spirit Level Indicator and Screw Compensator

varying temperatures, can be detected. The piece to be measured can be supported between the measuring points for any length of time until all parts arrive at an even temperature.

The headstock or slide *B* carries the measuring wheel *F*, which gives readings to 0.00001 inch, the graduations on the measuring wheel being so arranged that the indicated size can be read in decimals of an inch, the digits appearing in their proper rotation. For example, as shown in Fig. 14, if the size to be read is 0.31254, the first digit 3 is the highest figure disclosed on the left-hand side of the scale carrying the vernier. The second and third digits 1 and 2 are the highest main gradu-

ation on the measuring wheel below the zero line on the vernier, and the fourth digit 5 is the highest subdivision on the measuring wheel below the zero line on the vernier, while the fifth digit 4 is that graduation on the vernier in line with any graduation on the measuring wheel.

The measuring spindle has a thread of the buttress form cut especially deep to provide for wear, and has a range of

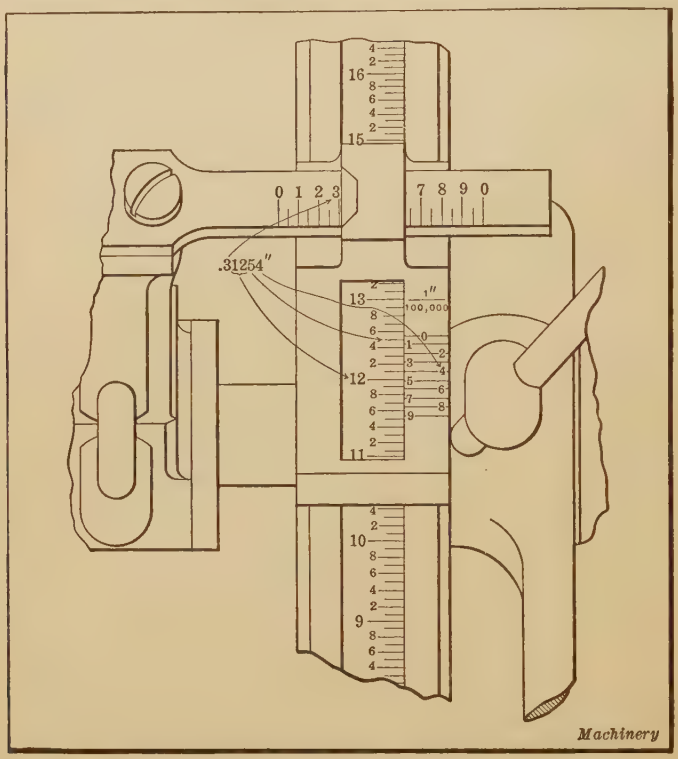

Fig. 14. Diagram illustrating Method of taking Measurements on Newall Measuring Machine

1 inch. The threaded portion of the screw and nut is equal to three times the length of range stated, so that the wear is even and accuracy of pitch is maintained. An automatic adjustment is also provided which maintains an even tension on the measuring screw by keeping the effective faces of the screw and nut in contact. It obviates backlash and facilitates accu-

rate reading. A knurled nut on the end of the spindle provides for the rapid movement of the measuring screw. This is used until sufficient pressure has been applied through the piece being measured to bring the indicating bubble into motion. For a sensitive movement, a fine adjusting screw is provided which is carried on an arm that can be clamped onto the measuring wheel at any point by an eccentric. This screw, the thrust of which is taken against the front horizontal bar, gives the slow motion necessary. The front horizontal bar is also used as a stop when it is desired to compare a number of parts which have been made to accurate dimensions.

Owing to the great difficulty encountered in making the pitch of a screw absolutely accurate for its entire length, a compensator arrangement is provided. This consists of a secondary screw of the same pitch as the measuring screw, cut on the rear end of the spindle. In contact with this screw is a roller held in a lever *G*, Fig. 13, and mounted in such a manner that any undulation on the crest of this thread imparts through lever *G* a forward or backward movement to the vernier scale *H* which is mounted on the vertical arm. In this way, any inaccuracies in the pitch of the thread are compensated for.

Operation of Newall Measuring Machine. — In setting this machine, the first step is to ascertain the amount of free movement in the anvil *I*. This is determined by bringing the headstock *B* and tailstock *C* together, so that the measuring points come into contact, and then observing, by rotating the measuring wheel *F* forward, the number of graduations passed in moving the bubble of the spirit level indicator *E* from its resting position. A small adjusting screw is provided underneath the rear end of the vial for returning the bubble to the resting position. Assuming that the free movement of this vial is 0.01 inch, the vertical arm carrying the scale *H* and the vernier is swung around to a perpendicular position, or inclined a little to the front of the machine, if more convenient for the operator, and the measuring wheel set to read about 0.01 inch. Before doing this, however, it is necessary to see that the measuring faces of the screw and anvil are perfectly clean and that

the headstock and tailstock are securely clamped to the bed. Then the measuring screw is advanced until the indicator bubble again reaches the measuring position and the reading will be somewhere near zero. The vertical arm is then adjusted so as to place the zero graduation on the vernier in direct line with the zero graduation on the measuring wheel, and the machine set at zero. It is advisable, however, to release the measuring screw and advance it again to check this final setting, when any slight inaccuracies may be corrected by a readjustment of the vertical arm. The machine should be so set that it is as free as possible from vibration and also from the effects of frequent changes of temperature. It is essential that it should not be exposed to the direct rays of the sun.

The foregoing description relates to the setting of the machine for measuring pieces up to 1 inch. For measuring pieces over 1 inch and without the use of end-measuring rods for setting the machine, the following method should be employed: The tailstock *C* is moved along the bed to the left; then, through microscope *K*, it is set to the nearest graduation, on the rule on the bed, below the size to be measured, the headstock not being moved, but left as previously set to the zero point. In all cases of microscope settings, it is advisable to clamp the tailstock slightly until, by means of the sensitive movement obtained by the fine adjustment slide, the desired line on the rule is perfectly central between and parallel to the two hair lines in the microscope; then the tailstock can be firmly clamped in position. The part to be measured is held in supports between the measuring points, care being first taken to be sure that all points of contact are perfectly clean. Then, by advancing the measuring screw in the same way as has previously been described, until the bubble of the indicator assumes its central position, the size of the piece is read off on the wheel and vernier. When advancing the measuring screw, the knurled nut on the end of the spindle is turned until sufficient pressure has been applied to start the bubble from its resting position. Then the screw of the fine adjustment arm is turned. moving the bubble slowly to its measuring position, which is

the critical point in all operations of setting or measuring. The subdivisions on the vial of the indicator are intended for comparison only, but their approximate value may be determined by observation and calculation, if desired.

Should the alternative method — setting to end-measuring rods — be used, a rod of the nearest length to the size to be measured is inserted between the measuring points and the processes described in connection with setting to zero are repeated. The inaccuracy of such end-rods must be known, and they should be regularly examined to detect any alterations in length through wear or temperature changes. It is also imperative that all surfaces and working parts of the machine be kept clean and free from oxidization and dust. The lightest possible oil should be used for lubrication, clock oil being preferable, but if this cannot be obtained, paraffin oil should be used on the measuring screw. The accepted mean temperature at which verifications of standards are usually made is 62 degrees F. This is the temperature at which this machine is tested. The rules used on this machine are made in rectangular sections from invar steel, which is noncorrosive and only slightly susceptible to changes in temperature. This machine will measure to 0.000001 inch, owing to the extreme sensitiveness of the spirit-level indicator.

Liquid Indicator Measuring Machine. — A measuring machine that is used in the Laboratory of Technical Tests, Berlin, Germany, and is considered to be accurate within 0.000004 inch, is shown in Fig. 15. The great precision of this machine is obtained by connecting a movable plunger to a metal diaphragm, which acts upon a colored liquid. This diaphragm is carefully fitted into a cylinder, and connected with the cylinder is a graduated glass tube. The diaphragm is so sensitive that even the expansion of the object being measured, caused by touching it with the finger, is indicated by the height of the liquid. As far as possible, the temperature of the room is kept at 68 degrees F., and a thermometer forms a necessary part of the instrument. For gaging the work, an adjustable stand is used which is raised to hold the work, if cylindrical, with

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its axis in perfect alignment with the measuring jaws of the machine. The instrument, in addition, carries a graduated wheel about 10 inches in diameter.

The chief use of this machine is to compare parts with standards, and it is, therefore, not provided with a vernier scale. The method of using it is as follows: The standard

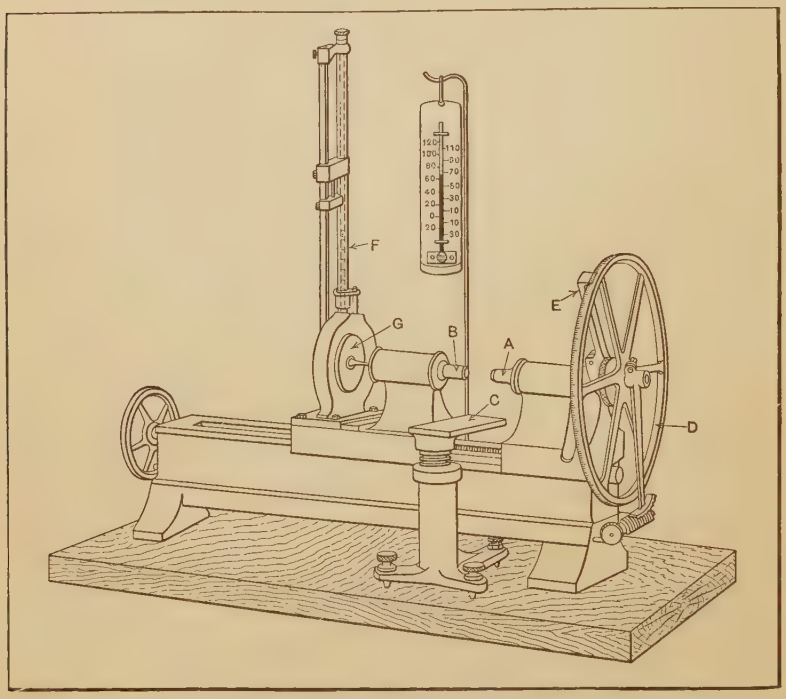


Fig. 15. German Type of Measuring Machine, capable of taking extremely Close Measurements

test piece with which the parts are to be compared is brought into contact with screw *A* and plunger *B*, being supported by stand *C*. Graduated wheel *D* is then set with its zero mark in line with the zero mark on arm *E*, and the height of the liquid in tube *F* is noted. The standard is then removed and the piece to be compared with it substituted. If the difference between the two pieces is minute, the most accurate method of determining it is by the height of the colored liquid. It is

highly essential, in making accurate measurements, that the pieces being measured be of the same temperature as the machine, and hence they should be allowed to remain between the measuring points until this condition is obtained.

Hartman Automatic Comparator. — The Hartman automatic comparator which is used by the International Bureau of Weights and Measures, France, is employed chiefly for comparing gages, and is not particularly adapted for originating measurements. It was built to insure exactness in the size

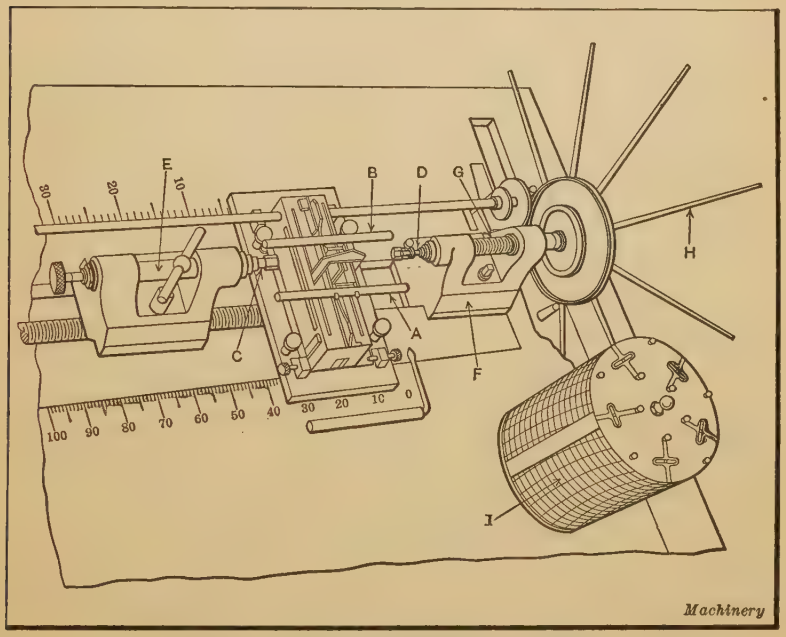


Fig. 16. Hartman's Automatic Comparator

of gages of the same type which are made by different firms, and is employed largely for testing gages used in gun manufacture. Referring to Fig. 16, which shows a diagram illustrating the principle upon which this machine is constructed, it will be noticed that two end-measuring rods *A* and *B* are being compared and are placed between the anvils *C* and *D*. The anvil *C* is held stationary in the tailstock spindle *E*, and the tailstock is free to slide along the base, which is graduated

for a length of 1120 millimeters (44 inches). The anvil *D* can be moved backward or forward in the head *F* by means of the left-handed screw *G*, which has a pitch of 1 millimeter (0.039 inch). The rotation of this screw, instead of being noted on a graduated sleeve, is measured by the position of the arms *H* which pass in front of the graduated chart *I*. The length of these arms is such that they describe a circle of 2 meters ($6\frac{1}{2}$ feet) in circumference, while the screw connected with the head makes one revolution and travels a distance of 1 millimeter (0.039 inch). The multiplication of the movement of the handles as compared with that of the screw is as one to two thousand. By dividing a portion of the circle on the chart into one thousand parts of 2 millimeters each (0.078 inch), when one of the arms has moved that distance — 2 millimeters — the surface of the screw will have moved 0.000039 inch.

In comparing the two end-measuring gages *A* and *B*, they are placed automatically, one at a time, between the anvils *C* and *D*, and their lengths registered on the chart *I* by the arms which prick a hole as they pass. The difference between the location of these marks gives exactly the difference between the length of the rods. This instrument is entirely automatic in its operation. The wheel carrying the arms is rotated by a motor. The gages to be measured and supported are held in carriers which operate automatically.

The Interferometer. — The interferometer is strictly a laboratory measuring instrument, and while it is indispensable for laboratory use, it is of little practical value to the average manufacturing establishment. The interferometer is used for measuring very small distances and angles in terms of wave lengths of light. It furnishes the most accurate known method for testing the uniformity of a screw or the perfection of a straightedge, making use of the phenomenon known as the "interference" of light. Light travels in waves, and a simple illustration of this is to compare a light wave to a rope which is fastened at one end and moved up and down rapidly at the other. In the movement of the rope, the distance from the highest part of one wave to the highest part of the next would be a wave

length, and the distance which the rope moves up or down from its middle position would be called its "amplitude." In the case of light vibrations, the amplitude determines the intensity of the light and the wave length determines the color. For example, light waves which are about 0.00003 inch long appear to the eye as red. The wave length of yellow light is about 0.000023 inch; of blue light, 0.000018 inch, etc. Two pieces of plate glass held in contact may be used to demonstrate the interference of light. If held at an angle to the light, color

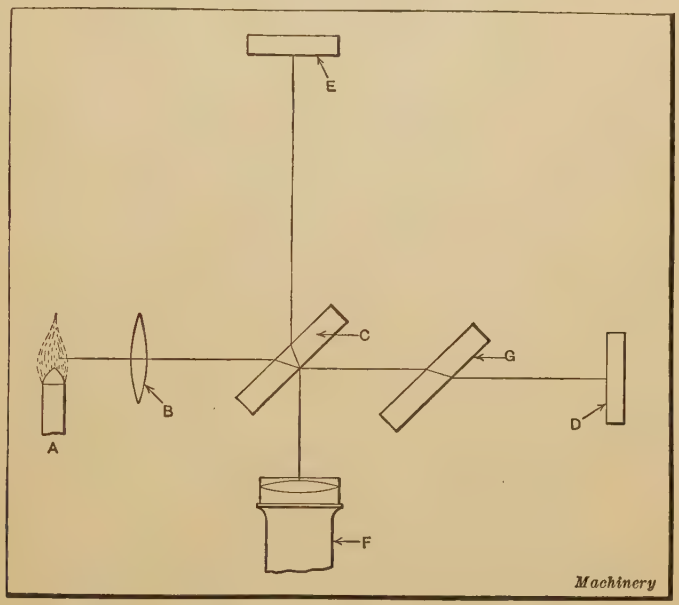


Fig. 17. Diagram illustrating Principle of Interferometer

bands will be noticed in circles and odd shapes throughout the plane of the two surfaces in contact. These colors indicate measurable variations in the surfaces from a true plane.

Principle of the Interferometer. — The Michelson interferometer, which is employed for precise laboratory measurements in the Bureau of Standards, is shown diagrammatically in Fig. 17. Artificial light is used with this instrument to produce the different light waves which indicate the variations from truth of the planes or other parts being measured. Sodium

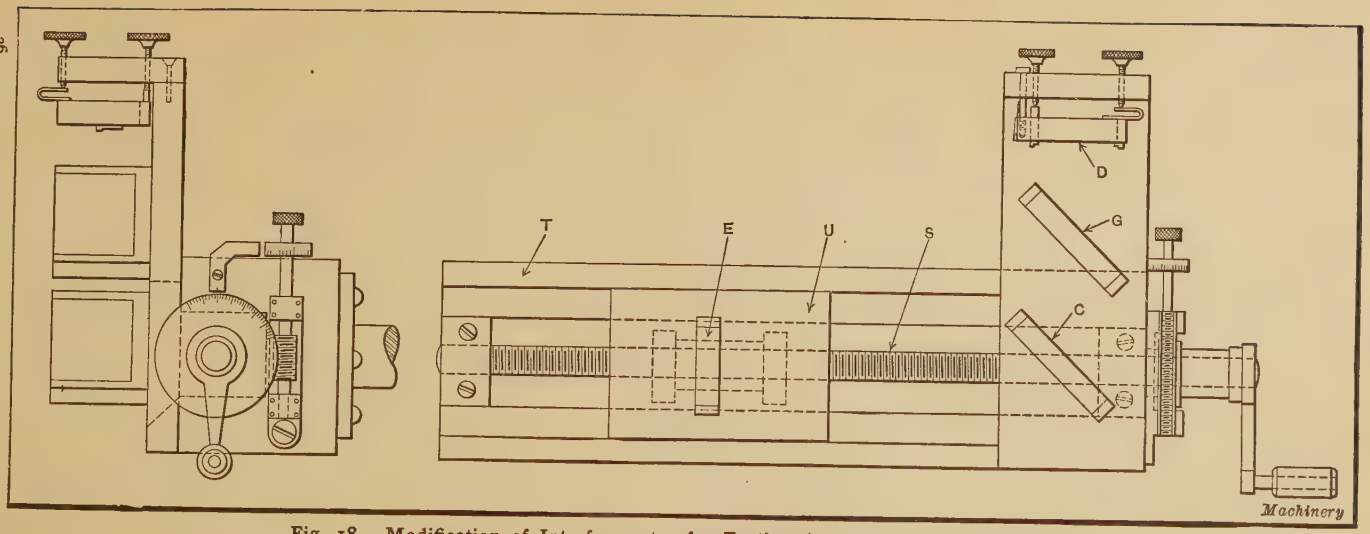


Fig. 18. Modification of Interferometer for Testing Accuracy of Screw Threads

light, the wave lengths of which are about 0.00002 inch, is generally employed. Referring to Fig. 17, *A* is a source of light rays, rendered approximately parallel by the lens *B*, that strike the glass plate *C* at an angle of about 45 degrees. Glass *C* is covered with a semi-transparent coat of silver which transmits some of the light rays to *D* and reflects some to *E*. These beams fall perpendicularly on the highly polished mirrors *D* and *E* and are reflected back to *C*. Some of the rays are reflected from *C*, and others are transmitted through *C* to the observing telescope or to the eye at *F*. The rays which are reflected by mir-

ror E have to pass three times through plate C before reaching telescope F. A compensator plate G is, therefore, put in the path of the other rays, so that the light reflected by D has to pass twice through G and once through C before it reaches the telescope. Plates C and G are cut from the same piece of glass so that they are of the same thickness, the original piece of glass having been ground and polished until its surface is plane and parallel to within from 0.000002 to 0.000005 inch, according to the accuracy of the measurements to be made.

When the paths of light from C to D and from C to E have been fixed nearly equal, the mirrors are so adjusted that the color fringes will appear as either horizontal or vertical lines. Then as one of the mirrors is displaced, the color bands pass in succession before the eye of the observer, who can count them as they pass the reference point — the crosshairs in the telescope.

Construction of the Interferometer. — The interferometer is constructed in different forms, depending upon the class of work for which it is to be used. For instance, an interferometer which would be used for checking the accuracy of angles would be constructed on a different principle from that used for testing the accuracy of straightedges or screw threads. For testing the accuracy of a screw thread, the interferometer would have a form somewhat like that shown in Fig. 18. The screw S to be tested is mounted in the bed T and is used to move the carriage U carrying the mirror E. The mirrors are adjusted so that the fringes appear in circles. This will happen when the fixed and movable mirrors D and E, respectively, are equidistant from plate C which divides the light, and when the reflection from mirror E in plate C is exactly parallel to the face of movable mirror E. The variation in the pitch of the screw is determined by the number of fringes that pass through mirror C. If the number of fringes is the same for each turn or fractional part of a turn of the screw, the screw is accurate; but if the number varies, the screw is inaccurate, the amount of the inaccuracy depending upon the difference in the number of fringes. By this method, inaccuracies are detected in a screw that are as small as 0.0000005 inch.

CHAPTER II

LIMITS AND TOLERANCES

Previous to the adoption of gages and inspection fixtures, the component parts of mechanisms were made by fitting one to another. As an illustration, take a gasoline engine and assume that the cylinders were finished by reaming. The pistons would be made approximately to size by caliper measurements and then fitted to the bore of the cylinders, the cylinders acting as a gage. In this way, of course, interchangeability is difficult, if not impossible. The question of having each part alike within given limits, however, has not always been considered practicable or necessary, and the first application of the interchangeable system was adopted in the production of rifles. In the past few years, the subject of gaging and inspection methods has received considerable attention. This has been due as much to the desire to reduce manufacturing costs as to the necessity for having all parts interchangeable.

It has been clearly demonstrated in plants where the interchangeable system has been properly applied that a less skilled grade of mechanics can be employed and still turn out interchangeable parts. It requires the services of a first-class mechanic to make a number of parts exactly alike, without a gaging system, but a second-rate mechanic can make a large number of parts exactly the same — within the required limits — and much cheaper, with a proper gaging and inspection system. Hence, the advantage gained by interchangeable manufacture is not only that all parts are made alike, but that the production costs are greatly reduced at the same time.

In the present chapter, the fundamental principles governing the setting of limits and tolerances for various classes of work will be dealt with in detail.

Development of Interchangeable Manufacture. — The original idea of making parts interchangeable must be credited to Le Blanc, a French mechanic, who about 1785 made rifle parts on an interchangeable basis, but the first practical application of the principle on a large scale is due to Eli Whitney, a manufacturer of Whitneyville, Conn., a small town just outside New Haven. Mr. Whitney first applied this principle to the production of firearms for the United States Government, with the object of being able to replace broken parts of firearms with new ones when in the field. In 1798, Mr. Whitney was given a contract for firearms which were produced on the interchangeable basis. The lock of these firearms was made by employing hardened templets to which the parts were accurately filed. About the same time Simeon North adopted the principle of interchangeable manufacture in the production of army pistols, and from the year 1800 great strides were made in this direction. The first complete system of interchangeable manufacture is credited to Elisha K. Root, a New England mechanic, who made a complete system of jigs, fixtures, tools, and gages for use in the Colt Armory at Hartford.

The Limit System. — The limit system which forms the basis of interchangeable manufacture is applied in a variety of ways in various manufacturing plants. In some cases, the limit system, as generally understood, is not applied in its entirety. For instance, parts which must fit together are made with certain allowances, but no tolerances are given to take care of unavoidable errors in the manufacture of parts. This cannot be called a limit system, because no limits are given. Consequently, a great deal more time and money is spent in making the parts than would be the case if the complete system were adopted. In cases where the limit system is not adopted, the parts are made to direct measurement, using standard measuring tools, and unless great care is taken and experienced workmen employed, considerable fitting and assembling is necessary. With a complete system of gaging and inspection, this fitting and assembling is almost, if not entirely, done away with, and manufacturing costs are thereby greatly reduced.

The advantages of the limit system are not always thoroughly appreciated, and in the following an endeavor will be made to explain some of the chief reasons why this system should be adopted where it is desired to produce parts cheaply as well as interchangeably.

Advantages of the Limit System. — The adoption of a limit system and the practice of working to limit gages has many advantages. In the first place, it makes an interchangeable product possible and eliminates the necessity of depending upon the judgment of the workman; and probably what is of still more importance, it reduces the amount of spoiled work to a minimum. The initial cost required to install the system in some cases is heavy, but when it is considered that a properly organized limit system greatly reduces inspection and manufacturing costs, the advantages to be gained will, generally, more than offset the cost involved. In adopting a limit system for ordinary work, it is necessary to take either the hole or the shaft as a standard. When holes are finished by grinding, it makes little difference which is decided upon. When the hole in the work is finished by reaming or similar tools, and can be duplicated in size with reasonable commercial accuracy, it is advisable to adopt the size of the hole as a standard. There are, of course, exceptions to all rules, and in some cases manufacturers using cold-rolled steel shafting find that it is preferable to use the shaft as a basis instead of the hole. As a general rule, however, the hole basis should be adopted.

Limit, Allowance, and Tolerance. — The expression "limit" as employed in machine shop work refers to the permissible tolerance in machine work. A shaft, for example, is required to be one inch in diameter; but it is generally unnecessary, in commercial work, to finish the shaft to a diameter of exactly one inch. It is, therefore, common practice to specify the "limit" — that is, the deviation from the true or nominal size which is permissible. The limit is generally stated by giving the amount that the dimension may be larger or smaller than the nominal size. The diameter of the shaft, for example, may be given as "one inch plus or minus 0.001 inch," which

means that the shaft will pass inspection if it is not more than 0.001 inch larger or 0.001 inch smaller than one inch. A common method of expressing this briefly on a drawing is to state the diameter as "1 ± 0.001." Another method is to give the dimension as "$\left\{\begin{matrix}0.999\\1.001\end{matrix}\right\}$."

There are a number of terms closely allied to the term "limit" used in the machine shop. Among these are "tolerance," "working tolerance," "permissible tolerance," "necessary tolerance," "clearance," "working clearance," "allowance," "working allowance," and "finish." Of these terms, all those containing the word "tolerance" signify the difference between the maximum and minimum limits; the terms containing the word "clearance" are equivalent to those containing the term "allowance"; and the term "finish" implies the final touch or elaboration that is given to the work, irrespective of the accuracy of the dimensions required. Therefore, as regards the dimensions, there are only three expressions necessary — "limit," "tolerance," and "allowance." The meaning of "limit" has been explained. "Tolerance" is the total difference between the maximum and minimum dimensions of the work. "Allowance," often termed "clearance," signifies the difference between the working parts to produce a certain fit and to provide for lubrication. The amount of the allowance depends upon the class of fit required, whether a running fit, sliding fit, push fit, drive fit, etc. The practice of making drawings which specify the exact amount of allowance between different parts, as well as the limit, is recommended. When this practice is followed, there can be no controversy when work is inspected, because everything is plainly stated on the drawing, and there is no opportunity for misunderstanding as to the accuracy required. The expression "a limit of 0.001 inch" should never be used, as it is indefinite, giving no idea of whether this limit is above or below standard size. It may mean either 0.001 inch above; 0.001 inch below; or possibly 0.0005 above and below standard size. When the limit is expressed as ±0.001 or ±0.0005 inch, there can be no mistake.

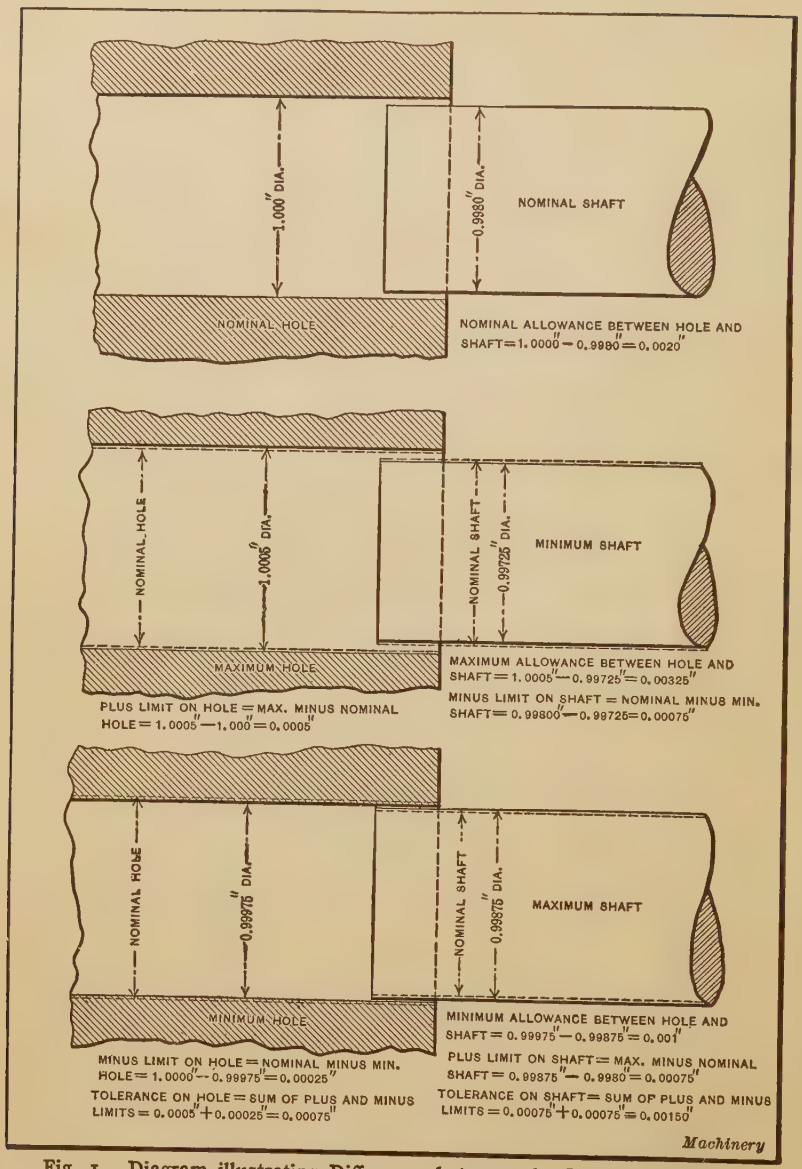

1.000" DIA.
0.9980" DIA.
NOMINAL SHAFT
NOMINAL HOLE
NOMINAL ALLOWANCE BETWEEN HOLE AND SHAFT = 1.0000" − 0.9980" = 0.0020"
NOMINAL HOLE
1.0005" DIA.
NOMINAL SHAFT
0.99725" DIA.
MINIMUM SHAFT
MAXIMUM HOLE
MAXIMUM ALLOWANCE BETWEEN HOLE AND SHAFT = 1.0005" − 0.99725" = 0.00325"
MINUS LIMIT ON SHAFT = NOMINAL MINUS MIN. SHAFT = 0.9980" − 0.99725" = 0.00075"
PLUS LIMIT ON HOLE = MAX. MINUS NOMINAL HOLE = 1.0005" − 1.000" = 0.0005"
NOMINAL HOLE
0.99975" DIA.
NOMINAL SHAFT
0.9987" DIA.
MAXIMUM SHAFT
MINIMUM HOLE
MINIMUM ALLOWANCE BETWEEN HOLE AND SHAFT = 0.99975" − 0.9987" = 0.001"
MINUS LIMIT ON HOLE = NOMINAL MINUS MIN. HOLE = 1.0000" − 0.99975" = 0.00025"
PLUS LIMIT ON SHAFT = MAX. MINUS NOMINAL SHAFT = 0.9987" − 0.9980" = 0.00075"
TOLERANCE ON HOLE = SUM OF PLUS AND MINUS LIMITS = 0.0005" + 0.00025" = 0.00075"
TOLERANCE ON SHAFT = SUM OF PLUS AND MINUS LIMITS = 0.00075" + 0.00075" = 0.00150"
Machinery

Fig. 1. Diagram illustrating Difference between the Terms Allowance, Tolerance, and Limit

To illustrate the expressions defined in the preceding paragraphs, suppose it is necessary to make a shaft with a good running fit in a bushing, as illustrated in an exaggerated form by the three detailed views in Fig. 1. The difference between the nominal diameters of the shaft and hole is 0.002 inch, which is known as the *allowance*. The *limits* on the diameter of the hole are −0.00025 inch and +0.0005 inch, and on the shaft, ±0.00075 inch, so that the *tolerance* on the hole is 0.00075 inch, and on the shaft, 0.0015 inch. For a nominal hole of 1 inch and a shaft of 0.998 inch, this gives a maximum hole of 1.0005 inch and a minimum shaft of 0.99725 inch — a difference of 0.00325 inch; and a minimum hole of 0.99975 inch and a maximum shaft of 0.99875 inch, a difference of 0.001 inch. From this it will be seen that the "set" allowance between the shaft and the hole is what is desired, but seldom obtained.

Setting Manufacturing Limits on Interchangeable Parts. — The setting of limits on work which must be made interchangeable is of vital importance. It is a subject which, generally, does not receive the consideration that it deserves. Many manufacturers set the limits much closer than is necessary to obtain interchangeability. When a part does not *need* to be made to more accurate limits than ±0.003 inch, this limit should be tolerated. Where greater accuracy is necessary, the limits should be closer.

The practice of specifying limits saves much needless expense. For instance, many manufacturers specify the length of a shaft in fractions of an inch and do not give any limits, with the result that the toolmaker or mechanic endeavors to bring the parts exactly to the size mentioned. This is a short-sighted policy, especially where $\frac{1}{64}$ inch more or less than the size given on the drawings would make no practical difference in the efficiency of the machine. Take also, for instance, gages, jigs, fixtures or other special tools used in the production of interchangeable parts. It is the practice of some concerns not to give any manufacturing limits on these tools, specifying that all dimensions should be exact. Hence, much time is consumed in making the tools, which even under the most favorable con-

ditions cannot be made exactly alike. Some go so far as to state that a plug or ring gage should be made exact, and have no limit of error at all; but this is impracticable, as it is almost impossible to make two parts exactly alike; a slight change in temperature will easily change a plug gage diameter 0.000025 inch. Several large manufacturing concerns have set limits on work produced in the tool-room with satisfactory results.

Methods of Establishing a System of Limits. — Many methods have been evolved for establishing a system of limits, and careful study of this subject has revealed the fact that practically no two manufacturers use the same system of setting limits, or give the same permissible amount of error in manufacturing. In some cases, the limits are stated directly on the drawing; in others, the size of the part is given either in fractions or in decimals of an inch, the method of giving the dimension being an indication of the permissible limit allowed. In some cases it is stated on the drawing that, where dimensions are given in fractions of an inch, a tolerance of $\frac{1}{64}$ inch above or below the dimension given is permissible. If the dimensions are given to two decimal places, the limit can be ± 0.005 inch; to three decimal places, ± 0.0015 inch; to four decimal places, ± 0.0005 inch; and to five decimal places, ± 0.0002 inch.

It is a difficult matter to decide upon the permissible error, as this depends entirely upon the character of the work and the conditions under which the parts are to operate. For instance, there are different classes of fits desired, such as push, drive, running, slide, force, etc. The variation or allowance between the female and male members depends upon several factors, among which might be mentioned: Diameter and length of hole, material, speed, load carried, etc. Consequently, no set rules can be established for this work. Several concerns, however, have established limits derived from practice, which, with proper judgment, can be used to good advantage. One system which has been adopted by the Newall Engineering Co. (England) is given in Tables I to V, inclusive.

There are several questions to be decided in setting limits on parts which must fit together. Ignoring, for the present, the method used in making the parts, which is an important matter, the two points which should be settled are, first, permissible maximum and minimum allowances between the shaft and hole; and second, manufacturing limits or tolerance for the hole. When these two points have been satisfactorily decided upon, it is a simple matter to establish limits on both the hole and the shaft. As an illustration, assume that it is necessary to obtain a running fit between the shaft and bushing shown in Fig. 2, and that the hole in the bushing is to be produced by reaming. The first question to decide is the maximum and minimum allowances. In this particular case, say

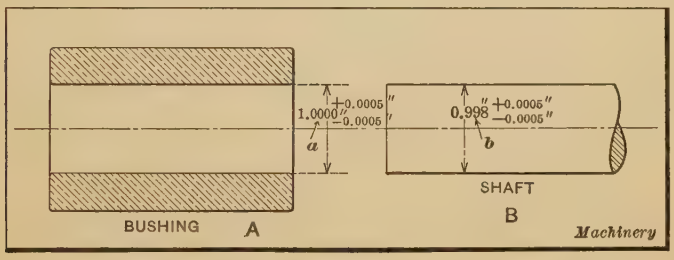


Fig. 2. Diagram illustrating Method of setting Limits for Obtaining Running Fit

that the maximum allowance is 0.003 inch and the minimum, 0.001 inch. The next question to decide is the permissible tolerance for the hole. As a standard reamer cuts slightly oversize, but, on the other hand, as the reamer may be slightly worn, make the hole as shown in Fig. 2, 1.000 inch ± 0.0005 inch. This gives a tolerance in the hole of 0.001 inch. Now, to set the limits for the shaft, subtract from the nominal diameter of the hole, or 1.000 inch, the mean allowance, or 0.002 inch. This gives a nominal shaft diameter of 0.998 inch. The limits can now be set for the shaft in a similar manner to that used for the hole, thus giving a manufacturing tolerance of 0.001 inch. Checking back to prove that the figures are correct, it is found that the largest hole is 1.0005 inch and the smallest shaft, 0.9975 inch, which gives an allowance between

these two sizes of 0.003 inch — the maximum permissible allowance. The minimum size of hole is 0.9995 inch and the maximum shaft, 0.9985 inch, which gives a difference of 0.001 inch, or the minimum allowance between the hole and the shaft. The manufacturing limits set on the work do not affect the original established allowances between the parts, when the method outlined above is followed, and there is no danger

Table I. Tolerances for Standard Holes
(Newall Engineering Co.)

Class	Nominal Diameters, Inches	0–½	9/16–1	1 1/16–2	2 1/16–3	3 1/16–4
A	Max. Limit	+0.00025	+0.00050	+0.00075	+0.00100	+0.00100
	Min. Limit	−0.00025	−0.00025	−0.00025	−0.00050	−0.00050
	Tolerance	0.00050	0.00075	0.00100	0.00150	0.00150
B	Max. Limit	+0.00050	+0.00075	+0.00100	+0.00125	+0.00150
	Min. Limit	−0.00050	−0.00050	−0.00050	−0.00075	−0.00075
	Tolerance	0.00100	0.00125	0.00150	0.00200	0.00225

Class	Nominal Diameters, Inches	4 1/16–5	5 1/16–6	6 1/16–7	7 1/16–8	8 1/16–9
A	Max. Limit	+0.00100	+0.00150	+0.00150	+0.00175	+0.00175
	Min. Limit	−0.00050	−0.00050	−0.00075	−0.00075	−0.00100
	Tolerance	0.00150	0.00200	0.00225	0.00250	0.00275
B	Max. Limit	+0.00175	+0.00200	+0.00225	+0.00225	+0.00250
	Min. Limit	−0.00075	−0.00100	−0.00100	−0.00125	−0.00125
	Tolerance	0.00250	0.00300	0.00325	0.00350	0.00375

Tolerance is provided for holes, which ordinary standard reamers can produce, in two grades, Classes A and B, the selection of which is a question for the user's decision and dependent upon the quality of the work required; some prefer to use Class A as working limits and Class B as inspection limits.

of having the minimum hole the same size as the maximum shaft, which is sometimes the case when the manufacturing limits are set in a haphazard manner.

Allowances for Various Classes of Fits. — In order to provide for various classes of fits, such as push, drive, force, etc., it is necessary to make certain allowances between the diameters of the hole and the shaft. As the hole basis is taken to be the standard in most cases, the size of the hole, therefore, is the first question to decide. Table I gives two lists of tolerances for standard holes varying from 0 to 9 inches in diameter

Table II. Tolerances for Running Fits
(Newall Engineering Co.)

Class	Nominal Diameters, Inches	0–½	9/16–1	1 1/16–2	2 1/16–3	3 1/16–4
R	Min. Limit	−0.00200	−0.00275	−0.00350	−0.00425	−0.00500
	Max. Limit	−0.00100	−0.00125	−0.00175	−0.00200	−0.00250
	Tolerance	0.00100	0.00150	0.00175	0.00225	0.00250
S	Min. Limit	−0.00125	−0.00200	−0.00250	−0.00300	−0.00350
	Max. Limit	−0.00075	−0.00100	−0.00125	−0.00150	−0.00200
	Tolerance	0.00050	0.00100	0.00125	0.00150	0.00150
T	Min. Limit	−0.00075	−0.00125	−0.00150	−0.00200	−0.00225
	Max. Limit	−0.00050	−0.00075	−0.00075	−0.00100	−0.00100
	Tolerance	0.00025	0.00050	0.00075	0.00100	0.00125

Class	Nominal Diameters, Inches	4 1/16–5	5 1/16–6	6 1/16–7	7 1/16–8	8 1/16–9
R	Min. Limit	−0.00575	−0.00650	−0.00675	−0.00700	−0.00750
	Max. Limit	−0.00300	−0.00350	−0.00350	−0.00350	−0.00375
	Tolerance	0.00275	0.00300	0.00325	0.00350	0.00375
S	Min. Limit	−0.00400	−0.00450	−0.00475	−0.00500	−0.00550
	Max. Limit	−0.00225	−0.00250	−0.00275	−0.00275	−0.00300
	Tolerance	0.00175	0.00200	0.00200	0.00225	0.00250
T	Min. Limit	−0.00250	−0.00275	−0.00275	−0.00300	−0.00300
	Max. Limit	−0.00125	−0.00125	−0.00125	−0.00150	−0.00150
	Tolerance	0.00125	0.00150	0.00150	0.00150	0.00150

Running fits, which are the most commonly required, are divided into three grades: Class R, for engine and other work where easy fits are wanted; Class S, for high speeds and good average machine work; Class T, for fine tool work.

Table III. Tolerances for Push Fits
(Newall Engineering Co.)

Nominal Diameters, Inches	0–½	9/16–1	1 1/16–2	2 1/16–3	3 1/16–4
Min. Limit	−0.00075	−0.00075	−0.00075	−0.0010	−0.0010
Max. Limit	−0.00025	−0.00025	−0.00025	−0.0005	−0.0005
Tolerance	0.00050	0.00050	0.00050	0.0005	0.0005

Nominal Diameters, Inches	4 1/16–5	5 1/16–6	6 1/16–7	7 1/16–8	8 1/16–9
Min. Limit	−0.0010	−0.0010	−0.00125	−0.00150	−0.00150
Max. Limit	−0.0005	−0.0005	−0.00050	−0.00050	−0.00050
Tolerance	0.0005	0.0005	0.00075	0.00100	0.00100

and known as "Classes A and B." Class A is preferred by some manufacturers as manufacturing limits, and Class B as inspection limits. In using the hole as a basis or standard, the shaft is made to suit the hole, depending upon the type of fit desired. The classes of fits used in ordinary practice are as follows: Running, push, drive, and force fits.

Running Fit. — Running fits, as specified in Table II, are divided into three classes or grades, known as "Classes R, S, and T." Class R is used principally for engine and other work where easy fits are required, and also for shafts running in several bearings or for a single bearing of unusual length. Class S is used for high speeds and good average machine work,

Table IV. Tolerances for Driving Fits
(Newall Engineering Co.)

Nominal Diameters, Inches	0–½	9/16–1	1 1/16–2	2 1/16–3	3 1/16–4
Max. Limit	+0.00050	+0.00100	+0.00150	+0.00250	+0.00300
Min. Limit	+0.00025	+0.00075	+0.00100	+0.00150	+0.00200
Tolerance	0.00025	0.00025	0.00050	0.00100	0.00100
Nominal Diameters, Inches	**4 1/16–5**	**5 1/16–6**	**6 1/16–7**	**7 1/16–8**	**8 1/16–9**
Max. Limit	+0.00350	+0.00400	+0.00450	+0.00500	+0.00550
Min. Limit	+0.00250	+0.00300	+0.00300	+0.00350	+0.00400
Tolerance	0.00100	0.00100	0.00150	0.00150	0.00150

and also for shafts running in a single bearing of ordinary length. Class T is for fine tool work, sliding shafts, and similar work. The limits given in Table II for running fits can also be employed for other than revolving fits where it may be advisable or necessary to limit the manufacturing error on the parts.

Push Fit. — Push fits, the limits for which are given in Table III, are for shafts that are forced into a hole by hand and that would be free to rotate without seizing, but not free enough to rotate under anything but a very slow speed. Usually there is sufficient friction between the hole and the shaft to prevent free rotation. Push fits are usually employed where one mem-

ber is fitted into another and then held in place with a key or pin.

Drive Fit. — Drive fits, Table IV, are used for shafts that are to be driven into holes either with a heavy hammer or with a light arbor press, and are distinguished from push fits in that shafts made with a drive fit can be easily driven into a hole, but will not be able to rotate.

Force Fit. — Force fits, Table V, are used for shafts which require either hydraulic pressure to force them into the holes, or for those in which the hole is expanded by heating for shrinking onto the shaft.

Table V. Tolerances for Force Fits

(Newall Engineering Co.)

Nominal Diameters, Inches	0–½	9/16–1	1 1/16–2	2 1/16–3	3 1/16–4
Max. Limit	+0.00100	+0.00200	+0.00400	+0.00600	+0.00800
Min. Limit	+0.00050	+0.00150	+0.00300	+0.00450	+0.00600
Tolerance	0.00050	0.00050	0.00100	0.00150	0.00200
Nominal Diameters, Inches	4 1/16–5	5 1/16–6	6 1/16–7	7 1/16–8	8 1/16–9
Max. Limit	+0.01000	+0.01200	+0.01400	+0.01600	+0.01800
Min. Limit	+0.00800	+0.01000	+0.01200	+0.01400	+0.01600
Tolerance	0.00200	0.00200	0.00200	0.00200	0.00200

Establishing Allowances and Tolerances for Various Classes of Fits. — The method used in establishing allowances and tolerances for a running fit has been described in a general way. Taking a concrete example, illustrated at *A* in Fig. 3, and using the limits of tolerance given in Tables I and II, assume the nominal hole to be 1.000 inch in diameter and use Class A limits. The hole here would be 1.000 $\left\{ \begin{matrix} +0.00050 \\ -0.00025 \end{matrix} \right\}$ inch. This gives a manufacturing tolerance of 0.00075 inch. The diameter of the shaft is then made smaller than the hole by making use of the limits given in Table II. Reference to this table will show that the shaft is made $\left\{ \begin{matrix} -0.00125 \\ -0.00275 \end{matrix} \right\}$ inch less than

the nominal hole. This gives a hole and shaft of the following dimensions: Maximum hole, 1.0005 inch; minimum, 0.99975 inch; maximum shaft, 0.99875 inch; minimum, 0.99725 inch.

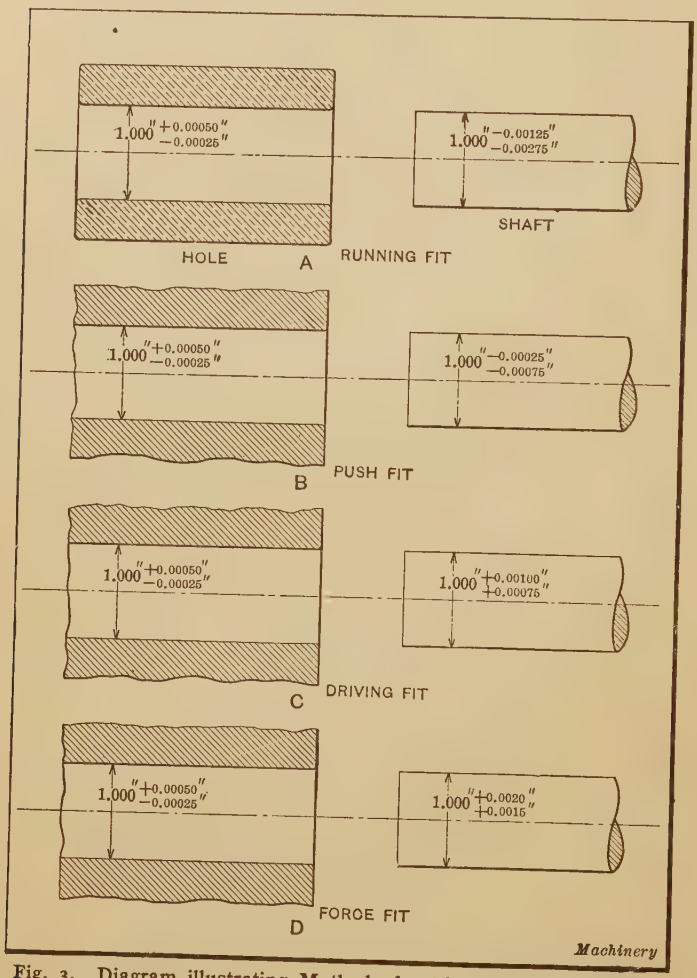


Fig. 3. Diagram illustrating Method of setting Limits for Various Classes of Fits

The difference or allowance between the minimum hole and maximum shaft is 0.001 inch, and the difference between the maximum hole and minimum shaft, 0.00325 inch. The tol-

erance between the maximum and minimum hole is 0.00075 inch, and the tolerance between the maximum and minimum shaft, 0.0015 inch.

In making a shaft which must be a push fit in a hole, the amount of tolerance for the shaft is considerably less than for an ordinary running fit. As indicated at *B* in Fig. 3, the tolerance for the shaft is made with a minimum limit of −0.00025 inch and a maximum limit of −0.00075 inch. This allows no theoretical difference between the maximum shaft and minimum hole; in other words, the smallest hole and the largest shaft are of the same dimensions, or 0.99975 inch in diameter. The difference between the largest hole and the smallest shaft is 0.00125 inch.

In making a drive fit, it is necessary to have the shaft slightly larger than the hole, so that the required amount of grip on the shaft will be obtained. As before, the hole is made with plus and minus limits, as shown at *C* in Fig. 3. The shaft is made larger than the hole and has a maximum limit of +0.001 inch and a minimum limit of +0.00075 inch. This produces a condition in which the largest hole is 0.0005 inch smaller than the largest shaft, and the smallest hole is 0.00125 inch smaller than the largest shaft. This insures in all cases that the parts will go together with a suitable driving pressure.

The conditions for a force fit are similar to those for a driving fit, with the exception that a greater allowance is made between the diameters of the shaft and the hole, in order to obtain a tighter union between the parts. As shown at *D* in Fig. 3, the shaft is made $1.000 \left\{ \begin{matrix} +0.0020 \\ +0.0015 \end{matrix} \right\}$ inch. This gives an allowance between the smallest hole and largest shaft of 0.00225 inch, and a difference between the largest hole and smallest shaft of 0.001 inch.

Methods of giving Limits on Drawings. — In setting manufacturing limits on interchangeable parts, various methods are adopted for expressing the limits of error to be tolerated. Expressions such as plus and minus, low and high, maximum and minimum are commonly used. There are two important

points to be observed when setting manufacturing limits: First, to so set these limits that the operator can clearly understand the drawing. Second, to express them in such a way that the draftsman who checks the drawing can conveniently tell whether the parts have been properly dimensioned or not.

A practical example, which will serve to illustrate this point, is shown in Fig. 4. Here a set of gears for the lower part of

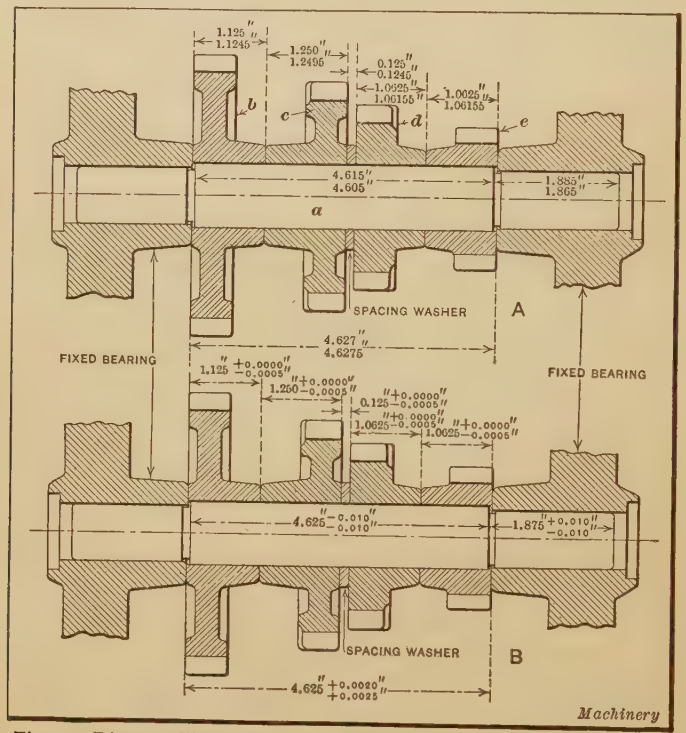


Fig. 4. Diagram illustrating Two Methods of dimensioning Drawings

an automobile transmission is shown in section; shaft *a* is shown supported in two fixed bearings. The four gears *b*, *c*, *d*, and *e* are keyed to this shaft and separated by a spacing washer. The washer provides for inaccuracies of the parts, and while this practice is not recommended, the example is so simple that it has been used in place of a more complicated one.

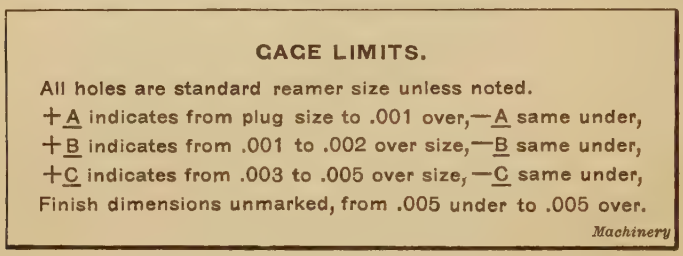
In Fig. 4, two methods are used for dimensioning the parts.

As shown at *A*, the minimum and maximum sizes or widths of the gear shoulders are given and the minimum and maximum distances between the bearings. In giving the dimensions in this manner, it makes it extremely difficult for the checker to determine whether or not any mistakes have been made in dimensioning. It requires a careful addition of the different dimensions to find if the required allowance between all the gear shoulders and bearing faces has been provided. Assuming that the minimum allowance between all the gears and bearing faces is 0.002 inch and the maximum allowance, 0.005 inch, the method of setting the limits on the drawing would be as follows:

Inspection will show that there are five parts, so that the total manufacturing limits on the gears should not exceed 0.0025 inch, as a limit also must be provided for the distance between the bearing faces. In other words, there are six dimensions to take into consideration, allowing a limit of 0.0005 inch on each; this totals 0.003 inch, or the difference between the maximum and minimum allowances. As soon as this question is settled, it is a simple matter to place the limits on the different parts. For the gears, no plus limits are tolerated and a minus limit on each part of 0.0005 inch is provided. The dimension given on the drawing to represent the distance between the bearing faces is a nominal dimension and is equal to the sum of the gear shoulders and washer. But as a minimum allowance of 0.002 inch is necessary, the minimum distance between the bearing faces would be the nominal dimension, or 4.625 inches + 0.002 inch, and the maximum, 4.625 inches + 0.0025 inch. To show that this is correct, add the nominal dimensions on the gears and washer, which equals 4.625 inches, as the maximum. The minimum is 4.625 inches − 0.0025 inch, or 4.6225 inches. The maximum distance between the bearing faces is 4.6275 inches, and the minimum, 4.6270 inches. This gives an allowance between the minimum gear shoulders and maximum bearings of 0.005 inch, and an allowance between the maximum gear shoulders and minimum bearing faces of 0.002 inch.

Inspection of the two methods of giving these dimensions at *A* and *B* will show that the one illustrated at *B* is the simpler from the standpoint of checking the drawing. At *B*, no plus limit is allowed for the gears and no minus limit for the space between the bearings; hence, the checker can immediately see that these gears are to be made with a running fit between the bearing faces. In the case shown at *A*, this is more difficult to ascertain without actually checking up the different dimensions and ascertaining the allowance between the gear shoulders and bearing surfaces.

Limit System for General Work. — The system of limits described in the following paragraphs was devised for use in an engineering office which specializes on general machine design. The various machines designed are built in different


GAGE LIMITS.

All holes are standard reamer size unless noted.
+A indicates from plug size to .001 over,—A same under,
+B indicates from .001 to .002 over size,—B same under,
+C indicates from .003 to .005 over size,—C same under,
Finish dimensions unmarked, from .005 under to .005 over.

Machinery

Fig. 5. Form of Gage Limit System for General Work

factories, depending upon the client for whom the work is done, and often without supervision by the engineer; so it is evident that any system of limits used must be simple and readily understood. The method to be described also avoids the work required in placing the limit sizes on the drawing. This, of itself, is something of an item on any design requiring a considerable number of details. Experience, therefore, led to a tentative method that has been developed into a system, in no sense perfect, but one which can be readily used in general work, and which insures good work without fitting or questions as to fits; these are decided by the designer and indicated in a way that is easily understood by the workman. This result is accomplished by affixing, to all dimensions which require limiting, a plus or minus sign and a letter, *A*, *B*, or *C*, which

indicates the amount of variation; plus indicating over nominal size and minus indicating under size. A rubber stamp giving the data presented in Fig. 5 is used on each detail sheet and the various details are marked accordingly.

The gist of the method is this: If a dimension has a plus letter after it, it must be to size or over, within the limits called for by the letter. Similarly, if a dimension is followed by a minus sign, it cannot be oversize and may be under, according to the letter. A dimension without a plus or minus letter indicates that the size is nominal, and ordinarily careful work is all that is required. Slots and depressions that would be measured by a plug gage may be considered as holes, and come under the heading "all holes are standard reamer size unless

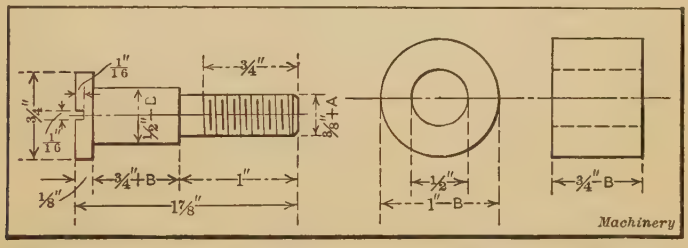


Fig. 6. Examples of Details showing Use of Gage Limit System

noted." Working on this basis, studs, shafts, slides, etc., are marked minus if a running fit, plus, if a driving or press fit, and the limiting letter according to the judgment of the designer. Both the plus *A* and the minus *A* dimension may ordinarily be considered as plug size, it being noted that the plus sign would be used where it was essential that the part be absolutely rigid, as in the neck of a stud where it fastens or is screwed into another part, making it integral; the minus sign would be used where a part is subject to frequent removal, as in a stop plug or other part where ease in removing is essential. Drilled holes may be dimensioned in thousandths of an inch, and cored holes should be specified. Fig. 6 will illustrate the application of this method to detail work. The roller shown is a running fit on the stud, and it is evident that the two details may be made independently and yet work together

without subsequent fitting. Limits are given, both on the length of the shoulder on the stud and on the width of the roller and this apparently departs from the general method described. It seems advisable, however, to allow variation when possible rather than absolute sizes, and in such cases as this, side clearance may be split up between the two parts with satisfactory results.

Under certain conditions, the limits shown in Fig. 5 cannot be used without modification. One machine, for example, may be of a character that prevents a maximum variation of more

CAGE LIMITS.

All holes are standard reamer size unless noted.
+A indicates from plug size to .0005 over,—A same under,
+B indicates from .0005 to .001 over size,—B same under,
+C indicates from .001 to .002 over size, —C same under,
Finish dimensions unmarked, from .003 under to .003 over.

CAGE LIMITS.

All holes are standard reamer size unless noted.
+A indicates from plug size to .005 over,—A same under,
+B indicates from .005 to .010 over size, —B same under,
+C indicates from .010 to .015 over size, —C same under,
Finish dimensions unmarked, from .015 under to .015 over.

Machinery

Fig. 7. Special Forms of Gage Limit System for Fine and Rough Work

than 0.002 inch; another may be of an exactly opposite character, in which a maximum variation of 0.015 inch or even more is allowable, without affecting the action. To meet these conditions, another rubber stamp may be used, and the values of the limiting letters changed, as shown in Fig. 7.

After a year or more, it has been found that little or no explanation is required when a drawing marked as described is put into the shop; moreover, the men seem to take kindly to it. In estimating costs, it is found valuable as an aid to the contractor in getting a closer figure than would be obtainable where nicety of finish would be a matter of guess work.

CHAPTER III

REFERENCE, WORKING, AND INSPECTION GAGES

A SATISFACTORY gaging system should be built around the basic reference and limit snap and plug gages. Reference gages are divided into three classes, as follows: Working gages for shop use; inspection gages for final checking; and gages used in testing and adjusting both working and inspection gages. Limit gages include two classes; namely, allowance and tolerance gages. Tolerance gages provide for reasonable error in workmanship, whereas allowance gages take care of the necessary difference in the sizes of two pieces which fit together; in this classification, the female and male gages are referred to collectively and not individually.

Reference Gages. — In addition to the reference blocks and rods shown in Figs. 1 and 2, Chapter I, reference gages are made in several other forms, the most common or conventional type being the standard plug and ring gage shown in Fig. 1 of this chapter. This type of gage is of little or no value in connection with interchangeable manufacture, as it is made to one standard size and can only be used for setting micrometers, calipers, and other measuring instruments. Owing to the great accuracy of this gage, it should not be used as a working gage. Plug gages are made to standard size within very close limits, and most manufacturers guarantee them to be within 0.0001 inch of standard size, although as a matter of fact they are often made considerably more accurate than this. The tolerance is over rather than under the standard, so as to provide for wear. The ring gage is then made to fit the plug and is not measured. Theoretically speaking, there is no difference between the diameter of the plug and the diameter of the hole in the ring, and they are put together only with great difficulty by an experienced gage-maker. It is done by coating the plug and the ring with a

film of light oil, placing them in alignment, and with a quick twist inserting the plug in the ring. The plug, however, must be kept in motion to prevent it from "freezing." If the ring and plug are allowed to remain stationary, relative to each other, they will stick to each other in a short space of time, and can only be separated by force. One way of separating them is to hit the ring quickly on the bench, and immediately pull out the plug, using a twisting action. This, however, also requires considerable experience.

Reference Limit Gages. — As mentioned, standard plug or ring gages made to one size are of little or no practical value in connection with interchangeable manufacture. Reference gages should be so made that both the inspection and working gages can be checked by them from time to time, to prevent the limits

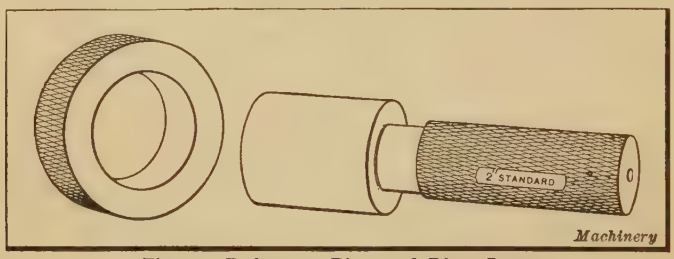


Fig. 1. Reference Plug and Ring Gage

changing due to the wear of the gages. A practical type of reference plug and snap gage for checking working and inspection snap and plug gages is shown in Fig. 2. Plug *A* has nuts on each end to prevent its use as a working gage. The limits are the same as on the working and inspection gages. In some plants, it is the practice to tolerate wider limits on inspection than on working gages. The reason for doing this is to reduce the amount of spoiled work, and also provide for the greater amount of wear on the working gages. When this system is used, it is necessary to provide two sets of limits, one for working and the other for inspection purposes. Reference gages to check the working and inspection gages should, therefore, be made to take care of this. The Johansson blocks can be satisfactorily used for this instead of reference gages.

As an illustration, assume that the difference between the "go" end of the working and inspection gages is 0.0005 inch; that is, the working gage is that amount larger than the inspection gage. The reference snap gage *B*, Fig. 2, can be used to determine when the working gage has worn down this amount; as soon as it has, it is turned over to the inspector, and the workman is supplied with a new gage. In this way, the workman is never working to the extreme limits, and the amount of rejected work is thereby greatly reduced.

Tolerances on Reference Gages. — Gages which are to be used as standards of reference should be made very accurately.

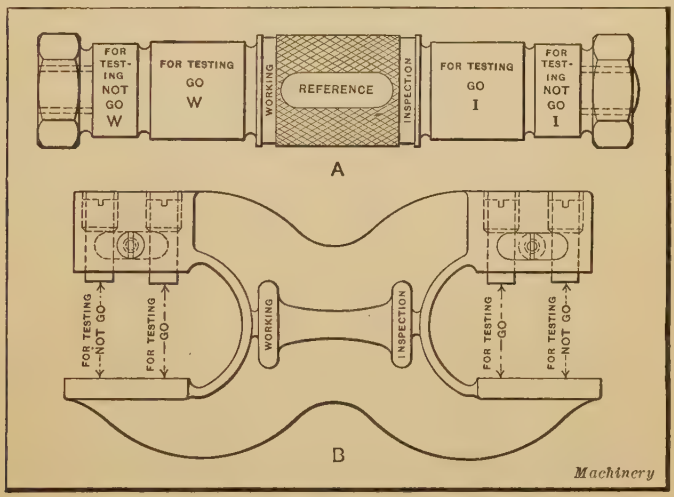


Fig. 2. Reference Limit Gages used in testing Limit Working and Inspection Gages

The permissible tolerances are dependent largely upon the class of work for which the gages are to be used, as well as the permanency of the gages. Some manufacturers make their reference standards from a good grade of machine or tool steel, and leave them soft. The reason for this is that soft steel has a lower coefficient of expansion than hardened steel that is not carefully seasoned. Soft reference gages are objected to on the ground that they are subject to wear and are easily dented, and must be handled with care. The well-known Johansson gages are made

from a nickel steel, and are guaranteed to be within a tolerance of 0.00001 inch to the inch. This extreme accuracy, however, is greater than can be ordinarily expected in regular reference gages, and, as a rule, the tolerances vary from 0.00005 to 0.0001 for sizes up to 1 inch, and from 0.0001 to 0.0002 inch for sizes up to 2 inches. This tolerance on the reference gage is distributed so as to take care of the wear on the working and inspection gages which are checked up by the reference gage. For instance, the "go" ends of a reference plug gage (*A*, Fig. 1) which would be used for checking the "go" ends of the working and inspection gages would be made to the required size minus the tolerance. On the reference snap gage which would be used for testing working and inspection plug gages, the tolerance would be added to the actual dimension required.

Erroneous Use of Standard Gages. — In some manufacturing plants, it has been the practice to use standard plug and ring gages as working gages. In fact, this has been done to such an extent that a gage on which there is no limit of tolerance is known as a "fixed" gage and is used in a manner similar to that in which a caliper is used. There are two reasons why a standard plug or ring gage should not be used as a working gage. In the first place, these gages are made very carefully and to extremely close limits, and if used as a working gage, their accuracy would soon be impaired. In the second place, as they are not provided with a working tolerance, a greater amount of time is consumed in finishing the work so that the plug will enter or so that the ring will go over it than would be necessary if a regular limit snap or plug gage were used. If both the plug and ring gages were used, they could no longer be considered as standard, as both would become inaccurate from wear. Furthermore, work which is finished so that these gages would fit it would be much more accurate than would ordinarily be necessary, and the time spent in bringing it to this degree of accuracy would be wasted. Therefore, "fixed" gages should not be used for other work than setting micrometers, calipers, etc.

Limit Working and Inspection Plug and Snap Gages. — The most common forms of limit working gages are illustrated by the

plug and snap gages shown in Fig. 3. The form in which these gages are made depends to a considerable extent upon the character of the work. The two types shown at *A* and *B* illustrate common forms of non-adjustable gages. The difference between the "not go" and "go" ends on the plug is the maximum error tolerated in the hole, and the difference between the sizes at the two ends of the snap gage, the maximum tolerance that is permitted on the shaft. The difference between the small end of the plug and the large or "go" end of the snap gage is the

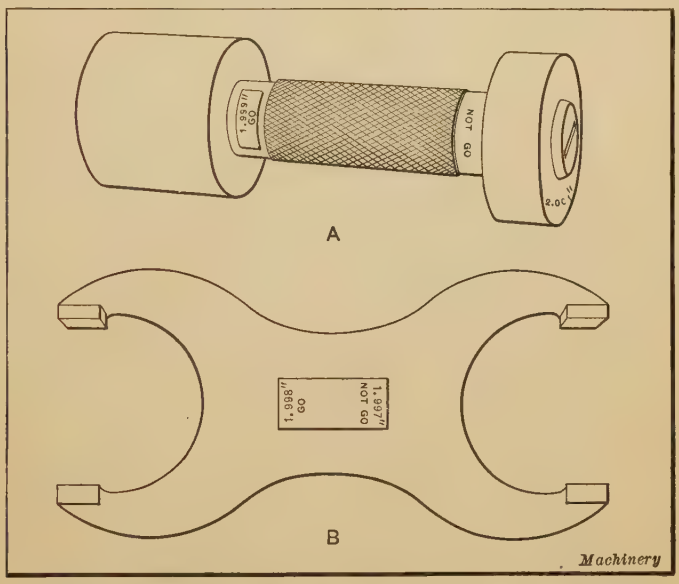


Fig. 3. Limit Working and Inspection Plug and Snap Gages

minimum allowance between the two parts — shaft and hole — and the difference between the large end of the plug and the small end of the snap gage is the maximum allowance between the two parts, assuming a running fit.

Tolerances on Working and Inspection Gages. — There seems to be some disagreement between gage manufacturers as regards the limits on plug and snap gages. Some manufacturers make all gages within a limit of ±0.0001 inch. This degree of accuracy is not always necessary, and, where the work can have consider-

able tolerance, it is desirable not to make the gages to very close limits; it would be preferable to make the plug gage, for instance, slightly large, so as to insure long life. The snap gage would be made correspondingly smaller for the same reason. This practice is being followed by one prominent concern which has adopted a unique system of plug and snap gages. The limits on the gages are governed entirely by the limits on the work. For instance, where the work must be held to a limit of within ±0.0005 inch, the limit on the plug or snap gage would be ±0.0001 inch. Where the limit on the work is ±0.002 inch, the limit on the gage would be ±0.0005 inch. On extremely accurate work, where a limit of only ±0.00025 inch is allowed, the gage must be

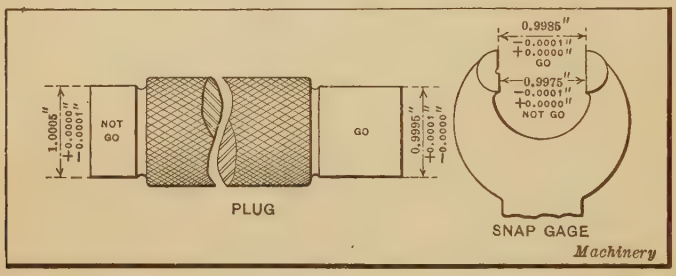


Fig. 4. Diagram illustrating Method of setting Manufacturing Tolerances on Working and Inspection Gages

made to a limit of ±0.00005 inch. This means that the life of the gage is considerably shortened.

Setting Tolerances on Working and Inspection Gages. — As an illustration of the point mentioned, Fig. 4 shows a plug and snap gage used in producing a shaft and hole that were required to have a good running fit. In this case, the maximum allowance between the largest shaft and the smallest hole is 0.003 inch, and the minimum allowance is 0.001 inch. The maximum tolerance on the shaft is 0.001 inch and the same tolerance is allowed in the hole. The difference, therefore, between the "go" and "not go" sizes on the snap gage is 0.001 inch. In manufacturing the snap gage, the "go" portion is made to a limit of 0.9985 $\left\{\begin{matrix} -0.0001 \\ +0.0000 \end{matrix}\right\}$. This provides 0.0001 inch for wear before the

gage would be worn down to the size indicated. On the "not go" end, it is not so important whether the limit is set plus or minus, although it is preferable to have it minus, which would prevent work almost up to the "not go" size from going in. On the plug, the "go" end is made 0.0001 inch large to provide for wear, and the "not go" end is made this amount small. In this way, the manufacturing limits are set so that the life of the gage will be increased without affecting the interchangeability of the work.

Advantages of Tool-setting Gages. — In working to limit gages, the tendency is for the operator to work as close as possible to the "go" end of the gage for fear of spoiling the work. This results in the parts going together with the minimum of freedom. The object, however, is to make the parts to the mean dimensions. Tool-setting gages which generally consist of hardened, ground and lapped blocks are used to set the cutting tools, and are made to the "mean dimension." These are used in connection with a hardened and ground locating block on the jig or fixture, and are employed principally on profiling and milling fixtures.

Life of Plug, Ring, and Snap Gages. — The life of a gage is governed by many conditions, among which might be mentioned: Tolerance allowed for wear; condition under which gage is used, whether for manufacturing or inspection purposes; character of material on which gage is used, whether brass, cast iron, steel, etc.; condition of work on which gage is used, that is, whether rough-turned, finish-ground, lapped, etc.; material from which gage is made, whether cast iron, carburized machine steel, tool steel, malleable iron, etc.; condition of measuring surface on gage, whether ground or highly finished and lapped; care used in applying gage.

Tolerance for Wear. — As mentioned, limit gages are usually made with limits that increase the life of the gage. In other words, on a plug gage, the "go" end is made with a limit larger than the size specified on the gage. The amount of this limit, in a general way, determines the life of the gage. As a case in point, on one extremely accurate piece of work, a limit of 0.00025

inch was the greatest tolerance. The plug gage was, therefore, made with a plus wear limit of 0.00005 inch, and as this gage was used in testing a hole finished by grinding, where considerable grit and dirt accumulated, its life was only one day of ten hours. In other words, a new gage had to be furnished every day. This, however, is an exceptional case, but it serves to illustrate the necessity of setting limits on the gage to provide for wear. The greater the limits on the work, the larger can be the tolerance for wear on the gage, so as to increase its life as much as possible. Furthermore, when the "go" end of a plug gage, for instance, is made larger than the lowest limit of tolerance, the machine operator is working closer to the mean or nominal dimension. In purchasing gages, most manufacturers do not give the subject of wear the attention it deserves, and generally demand of the gage-maker the exact sizes given, which do not provide for wear. This results in greatly increasing the gaging and inspection expense.

Conditions under which Gages are used. — The conditions under which a gage is used, that is, whether it is used for manufacturing or inspection purposes, governs, to a large extent, the number of pieces that can be gaged. It is, therefore, the practice of some firms to permit a larger limit on the working than on the inspection gages, and then interchange these gages as they begin to wear. For example, in one plant the machine operator is given the newest gage when it is of the plug variety, and the oldest when of the snap variety (solid type), and to keep close watch on the condition of the gages, this firm employs several men, known as "field" inspectors. The duties of these men are to cover the entire plant, inspecting the gages and replacing those that are worn out by new gages adapted to the work. When a job is turned in and the gages and tools sent with it, these gages are not allowed to be put in the tool storage or supply room, but are handed over to the field inspectors, who carefully go over the gages before they are stored. These field inspectors also see that the production and inspection departments are supplied with the proper gages. In this way, the machine operator is always provided with a gage with the closest limits, and, con-

sequently, the greatest amount of wear is obtained from the gages. Gages wear much more rapidly when used for manufacturing than when used for inspection purposes, so that the interchange of gages greatly reduces the amount of rejected work.

Influence of Material being Gaged on Life of Gages. — The kind of material being gaged also has considerable bearing on the number of pieces that can be gaged before the gage is worn beyond the required limits. Some materials, such as cast iron and aluminum, have a lapping effect, and wear the gage much more rapidly than either brass or steel. In one plant where a large number of aluminum fuse parts are manufactured, a careful inspection of the gages proved that in gaging 10,000 aluminum parts the wear on the gage was 0.0005 inch. It was also found that five times as many brass parts could be gaged with the same amount of gage wear; in other words, the same gage used on brass would inspect 50,000 parts before it was worn 0.0005 inch. Cast iron has a lapping effect somewhat similar to that of aluminum, but not so pronounced. In gaging cast iron, about 20,000 parts can be gaged with a wear of 0.0005 inch on the gage. The wear depends to a considerable extent upon the diameter of the work and its condition when gaged.

Influence of Condition of Work on Wear of Gages. — The condition of the work — whether rough or smooth — also has a governing effect on the life of the gage. Rough-turned work will wear a gage more rapidly than a ground surface, free from grit. As an indication of the life of an ordinary snap gage on work that is ground fairly smooth, it was found in one plant, where a careful record was kept, that 35,000 Russian shrapnel shells having a ground surface could be inspected with one gage before it was worn beyond the required limit. In this particular gage, 0.002 inch was allowed for wear, so that the gaging of 35,000 shells removed this amount of material from the surface of the measuring point on the gage. In this plant it was also found that solid snap gages did not give nearly as satisfactory service as those that were made with adjustable points. The latter could be readjusted every day to a standard plug, and the life could thereby be greatly increased. In another plant where

a similar limit was allowed on the gage and where the work was turned instead of ground, the number of parts inspected varied between 8000 and 10,000 before the 0.002-inch limit was removed from the surface of the gage. This shows that ground work has not nearly as abrasive an effect on the gage surface as rough-turned work; speaking in approximate terms, a gage can be used for only about one-third as many rough-turned pieces as it can for ground pieces.

Material used for Gages. — Gage-makers differ to a considerable extent in regard to the material from which gages should be made and its bearing upon the life of the gage. There are so many points to take into consideration in this connection that it is difficult to reach any definite conclusion. For instance, one point that must be considered is the total number of parts to be gaged; another, conditions which would make it unnecessary to inspect every part; still another, whether the gage is to be used for reference, working, or inspection purposes. It is generally conceded, however, that for plug gages used for manufacturing purposes, it is preferable either to make the gage from a good grade of machine steel and carburize it, or to make it from tool steel, hardened, seasoned, ground and lapped. Gages are seldom left soft unless they are used for reference purposes, or unless only a few parts are to be inspected. It is also the practice to leave thread gages soft.

The type of gage also has an important influence on the selection of material from which it should be made. For instance, a solid snap gage is seldom made from cast iron, either a malleable casting or a steel forging being used. Most manufacturers of solid snap gages make them from drop-forgings, when they are used for measuring up to 3 inches in diameter. Above this size, the gages are made from steel castings which are heat-treated, seasoned, ground and lapped to size. When snap gages are provided with adjustable points, it is the general practice to make the frame either from malleable castings or from cast iron. One prominent manufacturer of snap gages follows the practice of making the frame from cast iron of frail dimensions. This is done so that, in case the gage is

dropped on the floor, the frame will break rather than distort. In this way, any chance of the operator distorting his gage without knowing it is eliminated. The frame is also made of such a shape that it is impossible for the operator to "peen" the gage to fit the work. The difference between the lives of a solid snap gage made from fine-grained cast iron and one made from hardened steel is considered by many gage-makers to be extremely slight.

Condition of Measuring Surface and Life of Gages. — The condition of the measuring surface on the gage is not always considered a vital factor affecting the life of the gage. When it is understood, however, that it is practically impossible to secure a perfectly plane surface, the question of securing a smooth surface on the gage appears to be of greater importance. Some gages, especially the Johansson gages, have the property of adhering when wrung together with a force considerably greater than that due to atmospheric pressure on the areas in contact. This phenomenon has been attributed to molecular attraction, but investigation has shown that the adhesion is due to the presence of a very thin liquid film. Blocks made from hardened steel were prepared, each weighing an ounce and a half and having surfaces 0.7 square inch, polished flat to within $\frac{1}{100,000}$ inch of being a true plane. These blocks were then used to test the adhesive properties of different liquids. The contact faces were carefully freed from moisture and cleaned with alcohol. When the blocks were wrung together, they fell apart under their own weight, but as soon as a film of oil or other liquid was put between them, a force of 17 pounds for Rangoon oil, 20 pounds for lubricating oil, 29 for turpentine, and 35 for condensed water vapor was required to separate the blocks. From this test it was proved that it is impossible to obtain perfect union between two parts, and the only reason that they held together was because of the adhesive qualities of the lubricant or other liquid. Any machined surface, no matter how smooth, consists of humps and hollows, so that a surface which is brought down to the closest approximation of a true plane is one in which there

would be the greatest number of points in a common plane. It is, therefore, reasonable to assume that a gage made with

Table I. Estimated Life of Gages Used for 4.7-inch High-explosive Shells

Operation	Type of Gage	Estimated Life — Pieces Gaged
Rough Blank		
Length of billet	Crescent	100,000
Diameter of billet	Crescent	100,000
Forged Blank		
Diameter and length	Templet, snap	10,000
Cavity	Plug, flat	10,000
Diameter	Crescent	100,000
Wall thickness	Caliper	50,000
Length, total	Flat hook	100,000
Shell Body		
Trim base	Plunger, depth	30,000
Trim length	Fixture	30,000
Form nose	Flat, profile	11,000
Nose diameter	Crescent	100,000
Nose diameter	Ring	25,000
Body diameter	Crescent	100,000
Base diameter	Crescent	100,000
Band groove	Crescent	100,000
Base groove	Crescent, special point	100,000
Base groove	Flat, snap	5,000
Base groove	Flat, profile	11,000
Crimping groove	Flat, profile	11,000
Band groove	Flat, profile	11,000
Width band groove	Flat, limit	25,000
Base to bourrelet	Flat, profile	100,000
Bore for thread	Limit, plug	25,000
Thread recess	Flat, location	11,000
Thread plug	Limit	4,000
Counterbore	Limit, plug	25,000
Wall thickness	Concentric special	50,000
Band profile	Flat, limit	11,000
Base diameter	Ring gage	25,000
Diameter over band	Ring gage	25,000

a smooth measuring surface will wear much longer than one made with a rough surface.

Care used in Applying Gages. — It has been previously stated that gages used for inspection purposes wear much longer than those used as working gages. One reason for this is that the inspectors handle the gages much more carefully than do the workmen. In the first place, an inspector is seldom put on a piece-work basis, whereas a machine operator usually is. The chief point with the workman is to turn out as many parts as he can in the shortest possible time. To show that this is the case, a prominent concern made a careful test of the gages used by an experienced inspector and found that in inspecting 130,000 pieces the different gages were worn from 0.0015 to 0.003 inch. Similar gages used for manufacturing purposes were found to last only one-half as long as those used in the inspection department.

Life of Gages used on Ammunition Work. — The production of munitions in the United States has caused considerable attention to be paid to interchangeable manufacture and the use of limit gages. Parts for shells, fuses, etc., have been made by several different firms and then assembled in a separate plant, so that each part had to be made a duplicate of the other in order to enable assembling without fitting. Hence, each plant had to be equipped with a complete set of limit working and inspection gages. Several interesting points have come up in connection with the design and use of gages, one of which is the length of time that a gage can be used before it is worn beyond the set limits of tolerance. Some manufacturers did not equip their plants with the necessary number of reserve gages, with the result that they had to wait for a considerable length of time for deliveries from gage manufacturers. On account of this trouble, a close record was kept of the life of various gages, so that considerable data were soon available. Wells Bros. Co., of Greenfield, Mass., collected a large amount of information on this subject, some of which is presented in Tables I and II. The number of pieces tested by the various gages is based on data obtained from various munition manufacturers and represents a safe estimate of the approximate life. It should be noted in this connection that in very few

Table II. Estimated Life of Gages Used for 4.7-inch High-explosive Shells

Operation	Type of Gage	Estimated Life — Pieces Gaged
	Band	
Cut length	Fork, limit	100,000
Wall thickness	Fork, limit	100,000
Chamfer	Flat, profile	11,000
Hole	Plug, limit	25,000
	Base Plug	
Large diameter	Crescent	100,000
Thread diameter	Crescent	100,000
Concentricity diameter	Thread ring	20,000
Thread and groove	Crescent	100,000
Length thread and head	Flat, profile	11,000
Counterbore	Limit, cylinder plug	25,000
Thread bore	Limit, cylinder plug	25,000
Thread	Limit, thread plug	4,000
Thread and groove	Flat, location	11,000
Depth and width, slot	Special plug	25,000
Outer thread diameter	Crescent, thread	100,000
	Iron or Bronze Fuse Hole Plug	
Head diameter	Fork, limit	100,000
Flat for wrench	New Corey, limit	100,000
Thread and groove	Fork, special point	100,000
Thread outside diameter	Fork, limit	100,000
Concentricity	Ring, thread templet	20,000
Length and shoulder	Flat, limit	11,000
Internal thread groove	Flat, limit	11,000
Thread size	Fork, thread	100,000
	(Alternative) Die-cast Fuse Hole Plug	
Head diameter	Fork, limit	100,000
Socket	Plug, limit	25,000
Thread diameter	Fork, limit	100,000
Concentricity	Ring, thread templet	20,000
Thread in groove	Fork, special point	100,000
Length and shoulder	Flat, limit	11,000
Thread size	Fork, thread	100,000

cases were the gages provided with any tolerance for wear, so that their life was considerably shorter than would have been the case if a percentage of the tolerance on the work had been placed on the gage.

Types of Plug Gages. — Plug gages are made in a variety of forms and sizes, depending largely upon the shape and size of the work to be measured. For gaging small holes, they are generally made from a solid piece of steel, whereas for gaging larger holes, they are built up and so constructed as to make them easy to handle. A reference standard plug gage of the type shown at *A* in Fig. 5 is used chiefly for sizes up to 1 inch in diameter. For larger sizes, the gage generally has the form shown at *B*, and is made of a flat section from either a drop-forging or a steel casting, ground and lapped on the circular contour. The gages shown at *A* and *B* should not be used for working or inspection gages, but merely for reference purposes.

At *C* is shown a simple form of limit plug gage for comparatively small work. This consists of a hexagon handle provided with tapered holes in each end, into which hardened, ground and lapped plugs are fitted. The "go" plug is made considerably longer than the "not go" plug, to distinguish between them. Another type of plug gage shown at *D* is used for work of larger diameter, generally up to about 1 inch. This gage also has one end longer than the other, the longer being the "go" end of the gage. When a gage of this type is used on a grinding machine, the operator does not know how much material is to be removed until the "go" end enters the work. For this reason, it is the practice in some plants to taper the "go" end of the gage as indicated by the dotted lines *a*, making the end from 0.005 to 0.010 inch smaller than the regular "go" size or straight portion. This enables the operator to enter the gage into the work after he has taken his first roughing cut, and he can thus work much more rapidly; the chances of grinding the hole too large are also reduced, and at the same time the gage does not have to be used so frequently. When a plug gage of this kind is used, it is advisable to have the limit

on the "go" end as close as possible to the mean dimension and have the greater amount of tolerance on the "not go" end. The reason for this is that it is easier for the operator to work to the "go" end with this type of gage, and as it is the mean dimension that is always desired, it is advisable to

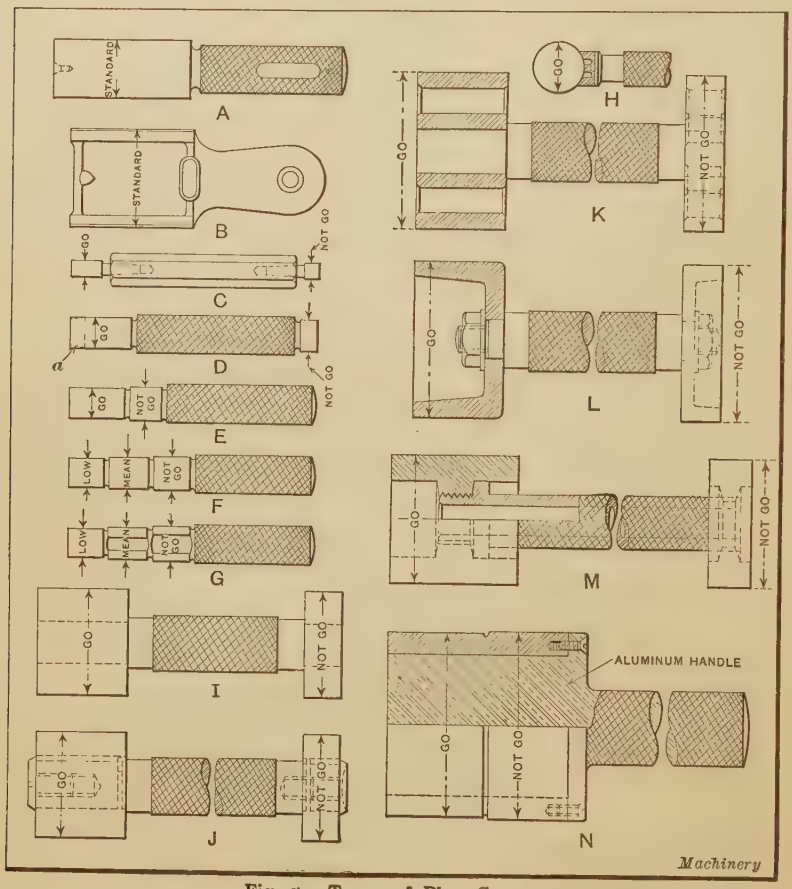


Fig. 5. Types of Plug Gages

have the limit here as close as practicable. Say, for instance, that the total tolerance between the "go" and "not go" ends is 0.002 inch; then the limit on the "go" end should be 0.00025 inch below the mean dimension and the remainder of the tolerance should be on the "not go" end.

It is the practice of some manufacturers to make a gage of this sort single-ended and use the taper as a limit. This practice is not recommended for the reason that, if the cylindrical part of the gage enters the hole, it would be too large. Consequently, it is necessary to have the plug enter to about one-half the way up the taper. This does not give the operator a chance to tell whether he has a bell-mouthed hole or not. Neither does it give him a chance to determine if the hole is truly cylindrical or tapered unless he removes it from the chuck and tests both ends.

When the work has a hole passing through it, the plug gage is sometimes made of the type shown at *E*. This gage has an advantage over that shown at *D* in that the "go" and "not go" sizes are on the same end of the gage, so that the operator is not likely to use one for the other. In order to facilitate grinding a hole to the correct size, the end of this plug gage can be tapered similarly to that shown by the dotted lines *a*, at *D*. An improvement over the gage shown at *E* is shown at *F*; this gage can only be used where the hole passes completely through the work. Here the gage is provided with three dimensions; first, the "go," second, the "mean" or exact dimension desired, and third, the "not go." In all manufacturing, especially on close work, the mean dimension is the one desired, and having a gage made with the three sizes, low, mean and high on one end, it is easy for the operator to work to extremely close limits with comparatively little trouble.

As a matter of fact, however, the plug gage is not a true detector of all the errors in the hole; for instance, a plug gage will not indicate whether or not the hole is truly cylindrical. It merely tests whether the hole is of the required size at a certain point, and for the majority of work this is sufficient. With a plug gage made as shown at *G*, it is possible to tell whether the hole is round or not within the required limit. The "mean" and "not go" shoulders are ground flat as shown, so that only two points of the circumference are to the required size. By turning the gage around, it is possible to determine the truth of the hole. This gage has been found satisfactory where

an extra degree of refinement is necessary and where the hole is not "three-cornered." This condition is only found when grinding work that is not properly balanced.

The gages shown from *C* to *G* are for inspecting small-sized holes up to 1 inch in diameter. When the holes are greater in diameter, a built-up gage is preferable in order to economize stock. One type of built-up gage is shown at *I*. This gage consists of "go" and "not go" cylindrical plugs fitted onto a soft steel shank by simply having the turned-down end of the shank slightly tapered and driving on the rings. This is a comparatively cheap gage to manufacture, and is satisfactory for the majority of work. Another type of built-up plug gage for large work is shown at *J*. In this case, the handle is made an easy fit in the holes of the "go" and "not go" plugs; the latter are fastened to the handle by means of screws, as shown, and are prevented from turning by pins which fit in a slot in the hole in the gage plugs. This type of gage is more expensive to manufacture than the type shown at *I*, but there is no danger of the plugs turning around or coming off while in the work. At *K* is shown a type of plug gage for gaging very large holes. The "go" and "not go" plugs are lightened by drilling six holes around the plugs midway between the outer circumference and the hole. A gage of this type must be carefully hardened to prevent cracking, and also seasoned to eliminate any internal strains that might develop after the gage had been in use.

An unsuccessful attempt to lighten a plug gage is shown at *L*. This type of gage has many disadvantages, one of which is the difficulty of hardening without springing it out of shape. Also, owing to the unequal strains set up in hardening, which are only partially removed by seasoning, it will not retain its shape when in use, and soon becomes out-of-round and inaccurate. It is also more affected by temperature changes than solid gages. A plug gage of this shape which is held in the hand for a few minutes will be found to be out of round about 0.0005 inch, simply because of the strains set up and the lack of sufficient support at the outer end. This gage is much lighter than a

solid gage, but the objections are so great that it is not recommended, although it has been used to some extent.

A gage which is made in a somewhat similar manner, but is so constructed that the strains are equally divided, is shown at *M*. Here the "go" and "not go" plugs are counterbored, and the mass of material is in the center. In hardening, the strains are more equally distributed throughout the mass, and, by careful tempering and seasoning, can be practically eliminated. The gage is also lightened by making the handle hollow, as shown. This type of construction is used by C. E. Johansson, maker of the well-known Johansson gage blocks. The hollow handles allow the air to pass through the gage when gaging blind holes, and the plugs are reversible, insuring long life. The measuring plugs are made of high-carbon Swedish crucible steel, hardened clear through and tempered and seasoned. The operations on these plugs consist in hand-forging, roughing to shape, hardening, tempering, rough-grinding, seasoning for a long period, and finally grinding and lapping. It is also claimed by this concern that making gages from low-carbon steel, case-hardened, is unsatisfactory, due to two causes. One is the rapid method of seasoning which is generally employed, and the other, the constant pulling of the hard case on the soft core. Gages that are hardened all through and carefully seasoned are not so likely to change as those that are case-hardened and improperly seasoned.

Very large plug gages are made of a type somewhat similar to that shown at *B*, except that they are provided with two diameters giving the plus and minus limits; or they are made of the bushing type shown at *N*, having an aluminum core and handle. A gage made of this type must be carefully hardened, and seasoned for a considerable period. It is also inadvisable to drive the sleeve onto the aluminum core. A better method is to hold the sleeve on the aluminum core by means of screws, as shown. This prevents distortion of the ring. The ring should be finish-ground and lapped while it is attached to the aluminum core, so as to prevent any liability of distorting it by assembling after lapping.

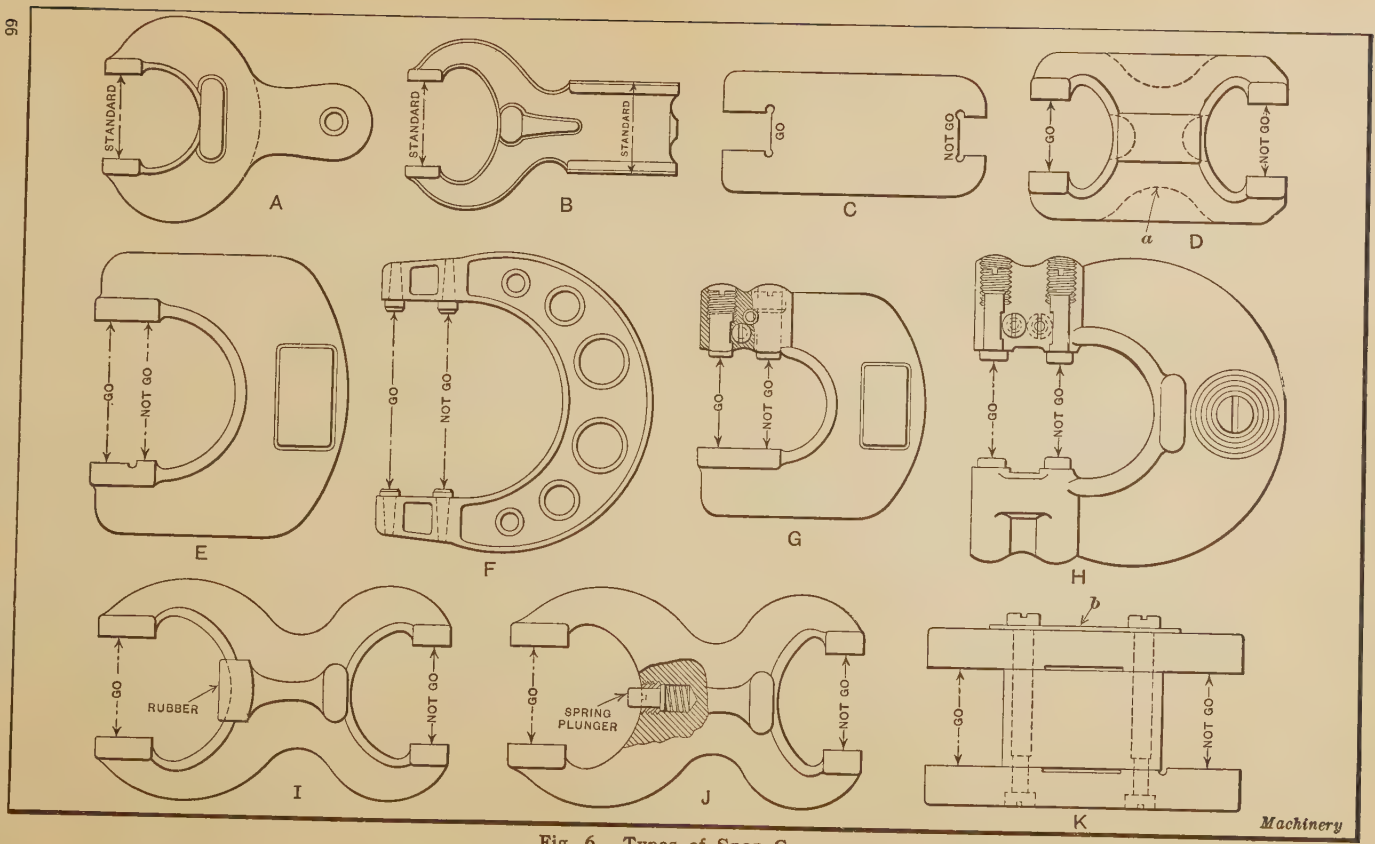


Fig. 6. Types of Snap Gages

Another plug gage which is comparatively cheap to manufacture, and also very accurate, is shown at *H*. This consists of two balls which are electrically welded to a handle. (One end of the gage only is shown in the illustration.) This gage has one serious disadvantage, in that its life is comparatively short, owing to the line contact which it presents to the work. There are many other types of plug gages used in various plants, but those shown in the foregoing illustrate the general principles of construction.

Types of Snap Gages. — Snap gages used in general manufacturing are made in three types; namely, solid, adjustable, and built-up gages. The adjustable type consists of a frame having adjustable anvils, and the built-up type is made from separate blocks. One type of snap gage, which is shown at *A* in Fig. 6, is known as a *standard* or *reference* gage. This gage is not provided with any working limit and is made to standard size, being used for reference purposes only. It is usually made from a high-carbon steel forging, carefully hardened, seasoned, ground on the measuring faces, and lapped. The use of this gage for other than reference purposes should be discouraged.

A type of gage which is a combination of snap and plug gages is shown at *B*. This is made and used in the same way as gage *A*. At *C* is shown a common type of limit snap gage which is made from sheet steel, varying in thickness from $\frac{1}{4}$ to $\frac{1}{2}$ inch, depending upon the diameter and character of the work being gaged. Snap gages of this type should have as wide a bearing surface as possible, as this greatly increases their life.

Another type of limit snap gage which is usually made from a forging, although sometimes from a malleable casting, is shown at *D*. This gage is made in two principal forms, one being shown by the full outline and the other by the dotted outline *a*. The dotted outline type of gage is used when the diameter to be measured is greater than 1 inch. Making a gage to this shape lightens it considerably. A single-ended type of limit gage is illustrated at *E*. This is provided with one flat jaw and one having the permissible tolerance on it.

Gages of this kind are usually made from drop-forgings and hardened. At *F* is shown a limit snap gage in which the body is made from cast iron with solid measuring points inserted. This gage is not provided with any adjustment, and it is necessary to renew the points when they become worn. This type is used only on very large work.

Another type of limit gage having only one jaw, but being provided with adjustable points, is shown at *G*. The adjustable points are prevented from turning in the holder by means of screws, as shown, the points having a flat side against which the heads of the screws rest. The anvils are adjusted in and out by means of the headless screws and are clamped by the screws passing through at right angles to the axis of the anvils. The forward faces of these anvils are beveled to prevent marring the work. Usually, on an adjustable snap gage of this kind, the points are not made absolutely flat, but are slightly convex. This insures that the measurement is always taken directly on the axis of the adjustable plug.

Still another type of adjustable point measuring gage, in which all four measuring points are adjustable, is shown at *H*. This type of gage is the Johansson patented limit adjustable snap gage. The measuring plugs are not threaded and do not turn in the body, having an end movement only, which prevents any possibility of their becoming cocked, as is the case with threaded plugs. They consist of plain cylinders of hardened steel, with flats on one side, and are lapped a snug, sliding fit in the lapped holes in the body. The ends which come in contact with the work and the faces of the adjusting screws are lapped square with the axis. The flat surface on the plugs and clamping screws prevent the plugs from turning in the body when adjustments are made. The rear end of each adjusting screw is provided with a screw driver slot, and the forward ends which come in contact with the plugs are lapped square with the axis. These screws should be sealed by the inspector after the gage has been set, to prevent the workmen tampering with it. The clamping screws are so arranged that they not only clamp the plugs, but also tend

to force them to a seat on the adjusting screws. The body of the gage is made from an iron casting of comparatively frail dimensions, so that, if it should be dropped, it is more likely to break than to be distorted. The frame is provided with an insulated rubber grip to prevent the heat of the hand from affecting the accuracy of the gage. By holding the gage with two fingers on the insulated grip, a sensitive touch can be attained, and at the same time the gage will not be distorted by the heat from the hand.

In using double-ended limit gages of the type shown at *D*, where the "go" end passes over the work, the gage will soon become inaccurate unless handled carefully, owing to the hammer effect on the throat of the gage when it hits the work. This causes a peening action which gradually opens the jaws. Different devices have been used for overcoming this. One, which is shown at *I*, consists in using a rubber pad fastened to the throat of the gage, as indicated. This takes the shock of impact of the gage on the work and prevents the peening action. Another method is shown at *J*, which consists of inserting a spring plunger in the throat of the "go" end of the gage. The "not go" end need not be made in this manner, as it is not supposed to pass over the work.

Rapid Inspection Limit Snap Gage. — A type of limit snap gage provided with an extension jaw, and which can be used either as a working or inspection gage, is shown in Fig. 7. This gage, which is patented by Wells Bros. Co., Greenfield, Mass., consists of a frame carrying a hardened, ground and lapped anvil plate and two adjustable measuring points. For snap gages having a capacity up to $1\frac{1}{4}$ inch, the frame is made from a drop-forging, while, for larger sizes, malleable castings are used. In the rear end of the frame is a hole which is elongated on the larger sizes to facilitate holding; there is also an extension base *A*, which can be used for holding the gage in a stand when it is desired to use it for inspection purposes. The lower jaw carries a hardened, ground and lapped anvil *B*, which is held in place by two screws as shown. This anvil greatly facilitates the location of the gage on the work, and makes

rapid inspection possible. The measuring points *C* and *D* for the "go" and "not go" sizes, respectively, are hardened, ground and lapped on the circumference and ends. The plugs are adjusted by screws *E* and *F*, and are clamped by a bar *G* and screw *H*.

Built-up Limit Snap Gages. — In many plants, and especially in those industries where a limit gage system is used extensively, considerable use is made of the built-up type of snap gage, one form of which is shown at *K* in Fig. 6. This

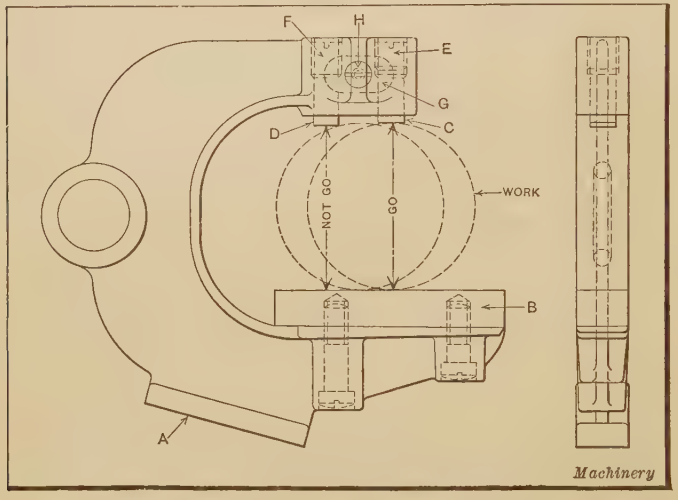
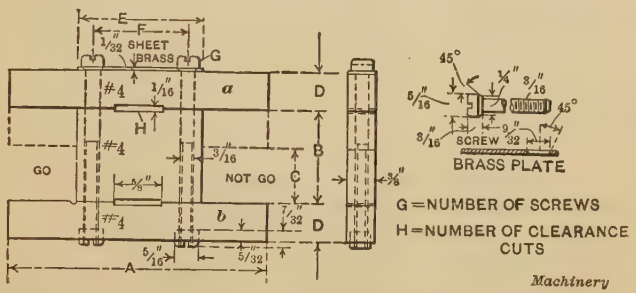


Fig. 7. Wells Bros. Co.'s Rapid Inspection Limit Snap Gage

gage consists of three members — one center spacing block and two measuring blocks. The form in which these measuring blocks are made differs in various plants. In some cases, one of the measuring blocks is split in half and the limit provided by grinding down half the center block the required amount for the "not go" end. The other system, which is shown at *K*, consists in having the limits on one of the measuring blocks. This type of gage is comparatively cheap to manufacture, as it can be finished complete on the surface grinder and is easily built up and taken apart for different sizes; it is only necessary to change the center block and the

tolerance on one of the side blocks to adapt it for different sizes. A brass plate *b* is fastened under the head of the screws to carry the job number and any other necessary data. It is the practice in some plants to put the "go" and "not go" dimensions on this piece, so that the operator knows what dimensions he is working to. Usually, however, this piece simply carries the job number, and is substituted by another when the gage is built up for a different size.

Table III. Proportions for Built-up Limit Snap Gages



No. of Gage	Dimensions in Inches							
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
1	2 1/16	1/4	0.00	1/4	1 5/8	1 1/4	2	1
2	2 3/16	1/2	1/4	5/16	1 5/8	1 1/4	2	1
3	2 5/8	3/4	1/2	3/8	1 5/8	1 1/4	2	1
4	3 3/8	1 1/4	3/4	1/2	1 5/8	1 1/4	2	1
5	5	2	1 1/4	5/8	2 1/2	1 1/16	3	2

Proportions for Built-up Limit Snap Gages. — Table III gives proportions for standard parts of built-up snap gages of the type shown at *K* in Fig. 6. This gage, as the table shows, is made in five sizes. The spacing blocks are made from machine steel and vary in thickness by $\frac{1}{32}$ inch; that is, the space between the maximum and minimum sizes *B* and *C* for each number of gage is divided into thirty-seconds of an inch. Hence, eight spacing blocks would be needed for gage No. 2. These spacing blocks are casehardened and ground and have the size stamped in the clearance cut. The top

block *a* is ground parallel, while the bottom block *b* is made to provide for the tolerance on the work and is stamped accordingly. Both these blocks are made from tool steel and hardened. When a snap gage of a certain size is desired, two blocks *a* and *b* and a spacer of the required thickness are obtained from the store-room and fastened together by screws which are standardized. A brass nameplate carrying the piece and operation numbers is put on, thus obviating the stamping of the gage proper; when worn, the gage can be taken apart, ground, lapped and put together again, and used indefinitely. The advantages of this type of snap gage for interchangeable manufacturing are obvious.

Taper Plug and Ring Gages. — The measuring of taper holes is practically always a fitting proposition. In fitting taper parts, the points that receive attention are the taper per foot or inch and the relative longitudinal positions of the two parts which fit together. In making a taper fit, the largest diameter of the hole and the largest diameter of the shaft must correspond within certain limits, these limits being measured lengthwise along the taper. The limits of tolerance allowed on a taper fit are dependent upon the taper, the methods used in holding the tapered parts, and their relative positions. The limits for a taper fit are seldom less than 0.010 inch, longitudinal dimension, and may be as much as $\frac{1}{8}$ inch on slight tapers.

Reference Taper Plug and Ring Gages. — The gages used for inspecting taper shafts or holes are usually of a simple type, the test being made largely by applying Prussian blue to either the plug or the ring; especially is this necessary when testing the degree of taper. Fig. 8 shows standard or reference taper plug and ring gages. The standard plug, as a rule, is provided with two or more shallow grooves to catch dust and dirt. The ring is also made with grooves, in some cases. When a taper plug is to be made for a standard taper, such as the Brown & Sharpe, Morse, Jarno, etc., the plug is made to the exact length specified, and the largest and smallest diameters on the plug are checked within limits very close to those given for the

different numbers of tapers. The same, of course, applies to the ring. When a plug is to be made for other than what is known as "standard" tapers, the size of the large end and the amount of taper are the only two governing points.

Setting Limits on Taper Gages. — As mentioned, the two chief points to consider in securing a taper fit between two parts is the fit of the taper and the relative longitudinal positions of the parts. In most cases, the largest diameter is taken as the standard size, but there are exceptions to this rule. As it is seldom necessary to have a taper end exactly at a shoulder on average machine work, the tolerance is, as a rule, not held to very close limits. There are cases, however, when the longitudinal position of one part on another must be held to close limits, and when this is the case, great care should be taken

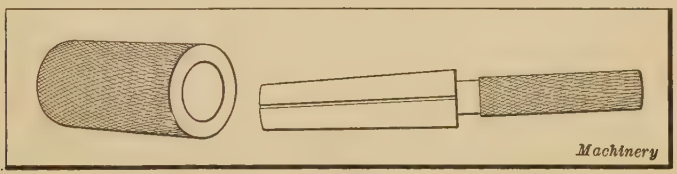


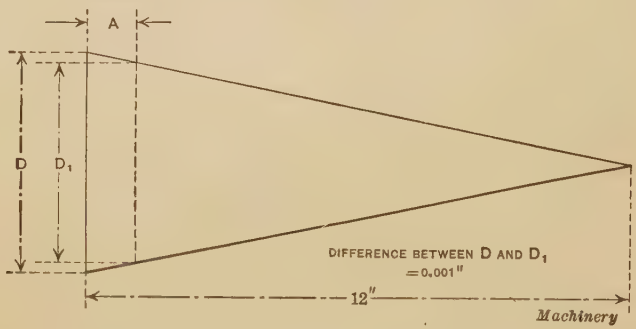
Fig. 8. Reference Taper Plug and Ring Gage

in setting the limits of tolerance. Knowing that it is possible to work to limits of ±0.001 inch on cylindrical work, this is also possible on taper work. Knowing also the tolerance on the longitudinal distance, the distance which governs the positions of the "go" and "not go" points for the various tapers per foot may be obtained from Table IV. This table forms a basis for the location of the limit points. For example, assume that the taper on a shaft and hole which must go together is $\frac{3}{4}$ inch to the foot, and that these two parts must be made on a strictly interchangeable basis in large quantities. Assume also that the relative longitudinal position of the two parts is not highly important. The question to be settled is the distance between the "go" and "not go" points on the male and female gages, respectively.

In order to provide as wide a limit as practicable, assume that the maximum tolerance for the hole and shaft, respec-

tively, is 0.001 inch. In other words, assuming that the nominal size is 1.500, the largest hole would be 1.501 inch, and the largest diameter on the smallest shaft, 1.499 inch. This gives an allowance between the diameters of the largest hole and smallest shaft of 0.002 inch. Hence it is necessary to know what longitudinal tolerance this represents in order to fix the limits on the male and female gages. Referring to Table IV,

Table IV. Lengths of Standard Tapers Corresponding to Difference of 0.001 Inch in Diameter



Taper per Foot		A in Inches	Taper per Foot		A in Inches
0.0625	(locomotive work)	0.1920	0.6020	(Morse s't'd)	0.0199
0.1250	(shell reamer arbors)	0.0960	0.6210	(American s't'd)	0.0193
0.1875		0.0640	0.6230		0.0192
0.2500	(standard taper pins)	0.0480	0.6250	(Morse s't'd)	0.0192
0.3750		0.0320	0.6260		0.0191
0.5000	(Brown & Sharpe s't'd)	0.0240	0.6300		0.0190
0.5161		0.0232	0.7500		0.0160
0.5430		0.0229	1.0000		0.0120
0.5910	(American s't'd)	0.0203	1.1250		0.0106
0.5920		0.0200	1.2500		0.0096
0.6000	(Morse & Jarno s't'd)	0.0200	1.5000	(S. A. E. s't'd)	0.0080

it will be noted that, for a difference of 0.001 inch in diameter, the length of the taper is 0.016 inch; hence, for a difference of 0.002 inch in diameter, the length of the taper is 0.032 inch. This amount is, therefore, the distance between the limit points on the male and female gages. When the taper is slight, say 0.250 inch to the foot, the length of the taper for a difference

of 0.001 inch in diameter holds good only when the parts are put together without pressure.

Reference to Fig. 9, which shows various types of limit taper plug and ring gages, will show how the limit for longitudinal position is set. In the case shown at *B* the plug has two lines on it, the lower one of which is the "go" and the other the "not go" position. The ring is cut away, as illustrated, and also has two lines on it, the lower one being the "not go" and

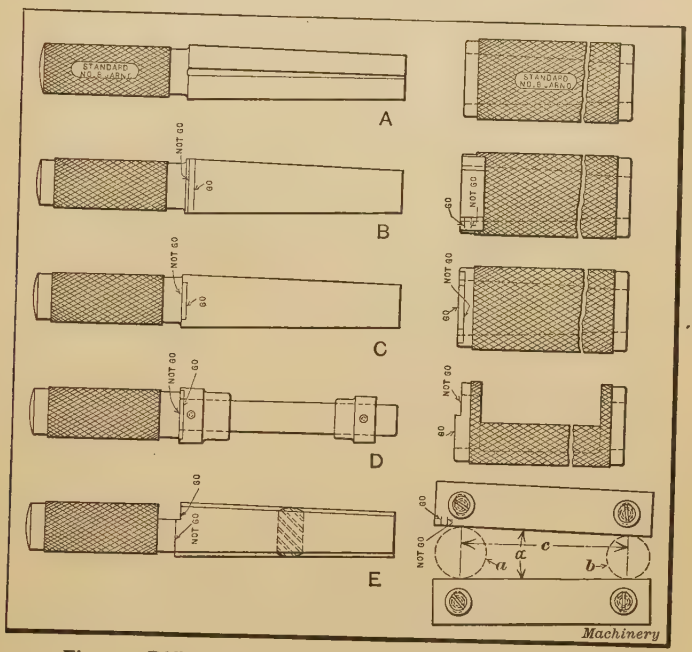


Fig. 9. Different Types of Taper Plug and Ring Gages

the other the "go" position. In setting the limits on the plug and ring gages, respectively, the "go" position on the plug should correspond exactly with the "not go" position on the ring. In other words, when the ring is placed over the taper plug, the "not go" line on the ring should coincide with the "go" line on the plug.

The kind of fit is governed by the amount of taper given to the part. For instance, on taper pins which will not work

loose, the amount of taper varies from $\frac{1}{16}$ to $\frac{1}{4}$ inch to the foot. For sockets which are required to drive cutting tools, the tapers vary from 0.500 to 0.630 inch to the foot. For locomotive frame bolts, the taper is generally $\frac{1}{16}$ inch to the foot. For arbors which carry shell reamers, etc., the taper is $\frac{1}{8}$ inch to the foot. For general automobile work, the accepted taper is $1\frac{1}{2}$ inch to the foot. When the longitudinal movement of two parts that go together is not to be greater than 0.010 inch, a taper not less than $1\frac{1}{2}$ inch to the foot is necessary, whereas, if a longitudinal distance has a tolerance of $\frac{1}{16}$ inch, a taper as small as $\frac{1}{2}$ inch to the foot would be satisfactory, when the longitudinal position is the only factor that need be considered.

Types of Taper Plug and Ring Gages. — The taper plug and ring gage shown at *A* in Fig. 9 is used only for reference purposes; *B* shows a type of taper plug and ring gage in which the limit is indicated by two lines. Another type of taper plug and ring gage is shown at *C*. Here, instead of having the limit lines on the plug and ring, the two members are milled down as shown, the distance between the two milled cuts being the amount of tolerance on the work. Another type of limit plug and ring gage is shown at *D*. In this case, the plug consists of a handle to which two bushings are attached, which are ground to the correct taper. With this type of plug, it is a comparatively simple matter to obtain a correctly machined taper hole without the use of Prussian blue or other fitting pastes. The taper in the hole can be easily tested by the wabble of the plug, as it rests in the hole at two points only, instead of its entire length. A similar idea is carried out on the ring, which is cut away and relieved in the center as illustrated.

In using plug gages of the type illustrated at *B* and *C*, difficulty is sometimes experienced, especially when the taper is slight, due to the plug "sticking" in the hole. One way of eliminating this is to make the plug as shown at *D*, but probably a more satisfactory way is to make it as shown at *E*. Here the plug is slabbed down on both sides, which allows free passage of the air; this will be found especially advantageous

in gaging blind holes. The only disadvantage of this plug is the difficulty of lapping it accurately. At the right-hand side of the illustration at *E* is shown a method of using two straightedges for testing a taper. This type of gage is generally used on the bench, being mounted on a stand, and is especially useful for originating tapers. In connection with two hardened and ground disks, as shown by the dotted lines, these tapered straightedges can be set very accurately to any degree of taper desired and used as a standard, if a standard plug gage does not happen to be available. When great accuracy is required in the measurement of tapers, this type of gage may be employed. It will be seen that if two disks of unequal diameters are held in contact or a certain distance apart, lines drawn tangent to their peripheries will represent an angle or taper, the degree of which depends upon the relative diameters of the disks and the distance they are placed apart. Referring to *E* in Fig. 9, assume that it is required to set the gage to a taper of $\frac{3}{4}$ inch to the foot, and that the disk *a* is 1.5 inch and *b*, 1.25 inch. It is desired to find the distance *c*, or the center distance between the two disks.

Rule: — Divide the taper per foot by 24 and find the angle corresponding to the quotient in a table of tangents; then find the sine corresponding to this angle, and divide the difference between the disk diameters by twice the sine. For example, let $\frac{3}{4}$ = taper per foot; 1.5 = diameter of large disk; 1.25 = diameter of small disk; and *c* = the required center distance. Then $\frac{0.75}{24} = 0.03125$, which is the tangent of 1 degree 47.4 minutes. Sin 1 degree 47.4 minutes = 0.03123; $1.50 - 1.25 = 0.25$ inch; $\frac{0.25}{2 \times 0.03123} = 4.002$ inches = center distance *c*.

A practical type of taper gage, which incorporates the principle illustrated at *E* in Fig. 9, is shown in Fig. 10. This gage is made up of two adjustable straightedges mounted on a cast-iron body having a convenient handle on one side by which the gage may be held or clamped when in use. The straight-

edges are made of tool steel, hardened, ground and lapped, and are adjusted either to a standard taper gage or by means of disks, as previously mentioned.

Taper Pin Gage. — A standard gage for testing taper pins is shown in Fig. 11. This gage is made so that it tests Nos. 7, 8, and 9 taper pins. It consists of two straightedges *A* and *B* fastened to a cast-iron base *C*. Located close to the largest diameter of each size of pin is a spring plunger *D* which is operated by the individual handles *E* for removing the pin after gaging. Lines *F* and *G* for each number indicate the

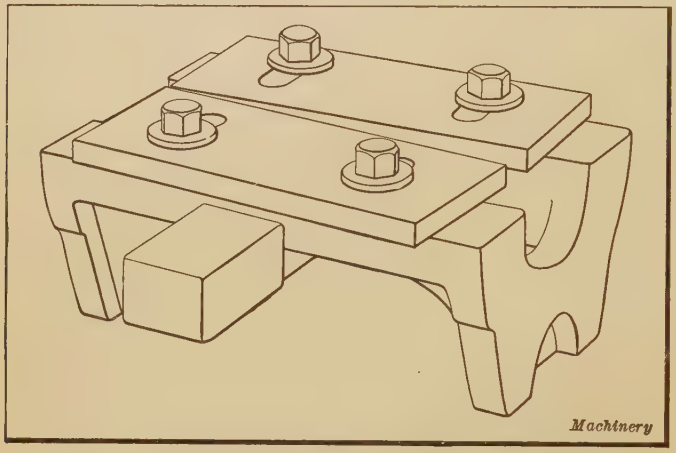


Fig. 10. Adjustable Taper Gage manufactured by Taft-Peirce Mfg. Co. incorporating Principle illustrated at E in Fig. 9

minimum and maximum sizes at the large end of the pins. In being tested, the pins are slid along the slot until they bear against the sides of the straightedge. If the large end passes the limit lines, they are rejected.

Gage for Screw Machine Work. — In the following paragraphs are shown a number of examples of gages from practice. A type arm pivot made on the automatic screw machine is illustrated in Fig. 12, and an interesting form of gage for testing the accuracy of these parts is shown in Fig. 13. The thin ends of this part constitute the main bearings of the pivot; the tolerance allowed is very small. Referring to the illus-

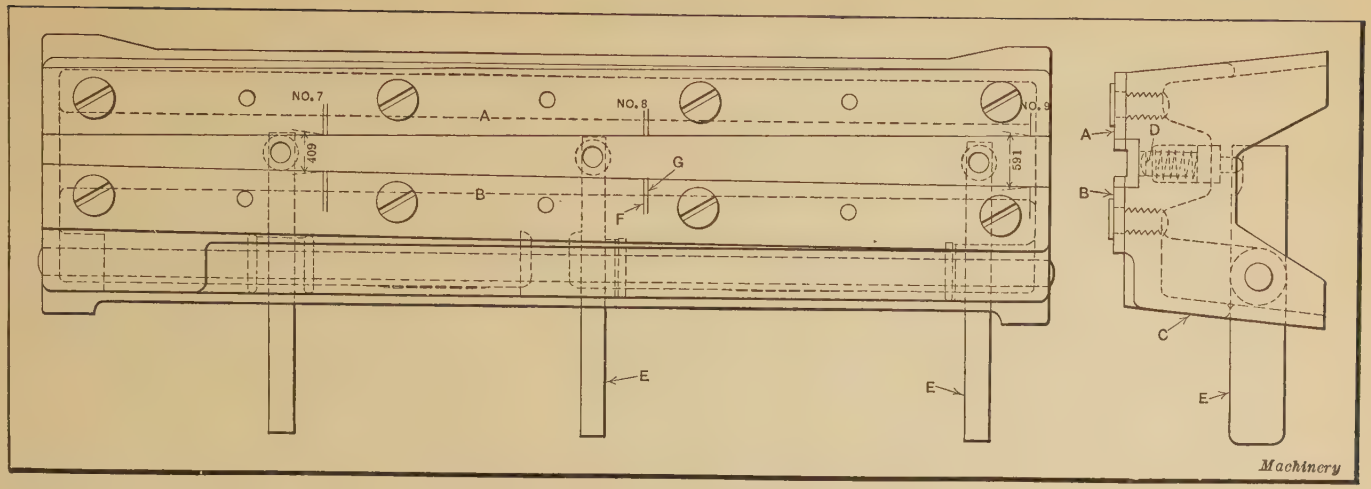


Fig. 11. Gage for Testing Standard Taper Pins

tration of the gage shown in Fig. 13, the block *A* is secured to the base by means of two screws and two pins, and it is drilled to receive the gage *B*. This gage is a press fit in the block *A*. A similar block *C* is secured to the base and drilled to receive the gage *D*. This block is of greater length in order to accommodate the spring which returns the gage to its original position after it has been moved back by the handle *E* to allow the work to be put in place. To check the dimensions of a piece of work with this gage, the inspector pulls back the lever which moves the gage *D* with it. This enables one end of the

type arm pivot to be slipped into the gage *B*, which has a hole in it of exactly the same shape as the end of the work to be gaged. The handle *E* is then released and the spring returns the gage *D* over the opposite end of the work. It will be seen from the illustrations that the limit of tolerance on these pins is between 0.0536 and 0.0540 inch, and the gage indicates whether the dimensions are within these limits by the position of the movable gage *D*. All screw machine operators do not have a micrometer graduated to 0.0001 inch, and this gage takes the place of such a micrometer with perfect satisfaction. Holes and slots are provided at the left-hand end of the gage for checking the dimensions of the large diameter and the length of the work.

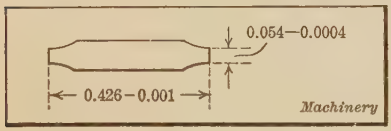


Fig. 12. Screw Machine Work to be Gaged

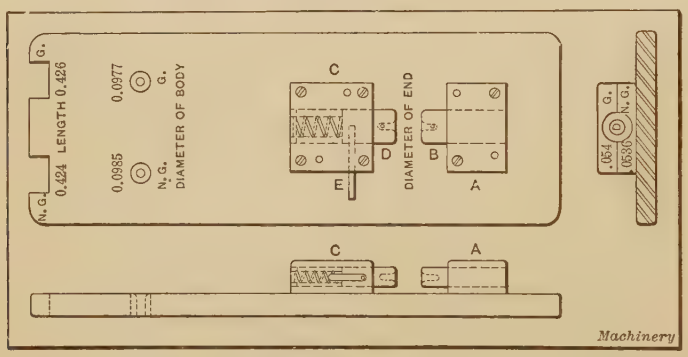


Fig. 13. Gage for Piece shown in Fig. 12

Limit Gage for Measuring Recessed Work. — The parts of a limit gage for measuring recessed work are shown in Fig. 14, together with an assembled view of this tool and an illustration showing how it is used. The plug *A* enters the hole in the body of the gage *B* which has a dovetail slide machined in it to receive the two gage plates *C*. Pins *D* fit in the holes in the plates *C* and also extend through the elongated holes in the cover-plate *E*. In using this gage, the operator takes hold of the two pins *D* between his thumb and index

finger and draws the sliding plates *C* back until the pins engage the inner ends of the elongated holes in the cover-plate *E*. The plug *A* is then pushed into the hole and causes the sliding plates *C* to move out from the center. There are two shoulders above the pilot on the plug *A*. In order that the work shall pass

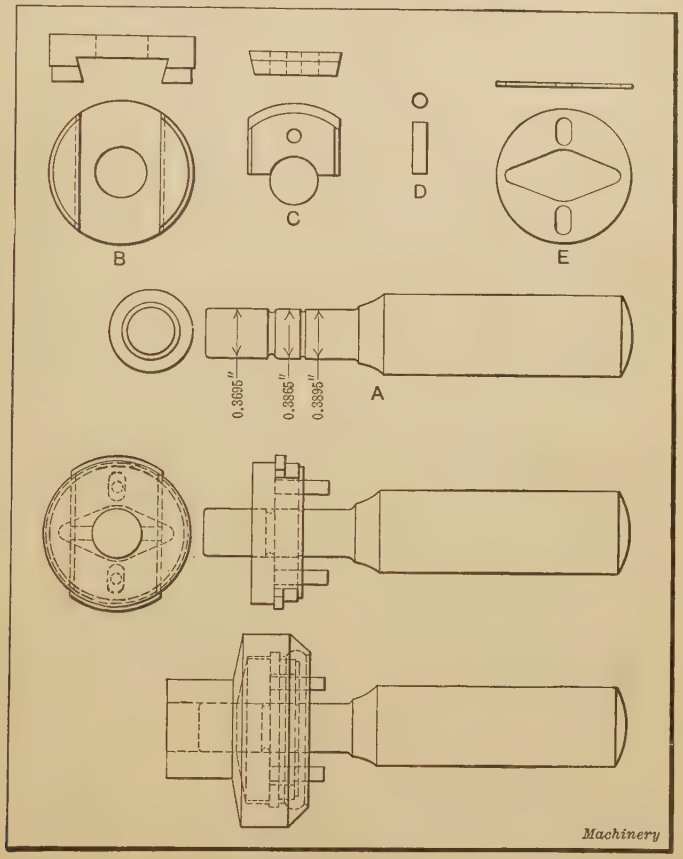


Fig. 14. Parts and Assembled Gage and its Application in gaging a Recess

inspection, it will be necessary for the first shoulder to enter the hole in the gage; but if the second shoulder can also be entered into the hole, it shows that the work is too large and results in its rejection. After gaging, the plug *A* is pulled out and the pins *D* drawn back so that the gage can be removed from the work.

In making this tool, the plug *A* is hardened, ground and lapped to the required size. The body *B* is next made with the dovetail groove to receive the sliding plates *C*, which are made in one piece to enable the hole to be lapped to size and the piece to be placed on a mandrel to grind the outer surfaces to the required diameter. Before hardening, the piece forming the two plates *C* is sawed almost through at the center from both sides, and after lapping the hole and grinding the outside, the piece is parted to form the two plates *C*. A gage

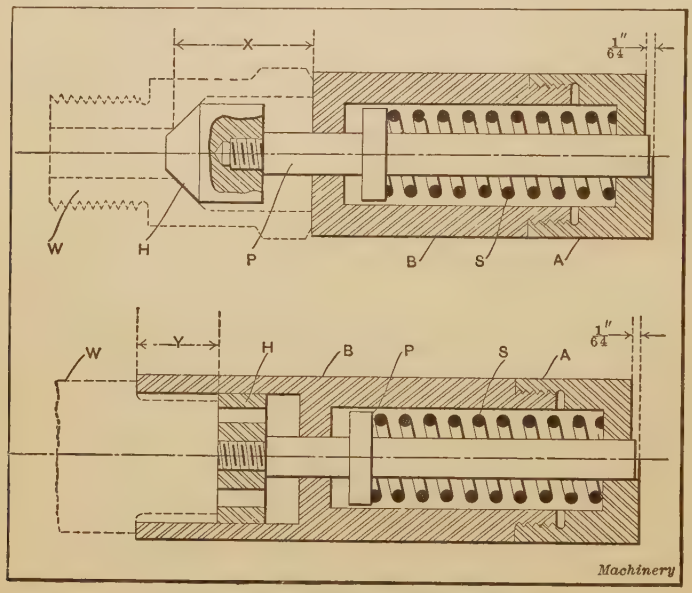


Fig. 15. Simple Forms of Limit Gages

of this type can be used to advantage in measuring a great variety of recessed work.

Inspection Room Limit Gages. — Two interesting limit gages are illustrated in Fig. 15. These gages are employed for inspecting parts that are produced at the rate of several thousand per day, and give perfect satisfaction. Both gages are built along identical lines. They consist essentially of a plunger *P*, plunger head *H*, plunger barrel *B*, spring *S*, and barrel cap *A*. The outer face of the cap consists of two planes accu-

rately ground within $\frac{1}{64}$ inch of each other, this being the limit within which distances X and Y are permitted to vary. The step or rise of $\frac{1}{64}$ inch thus formed on the cap A extends across the center of the cap end. In the upper illustration, the important dimension is the depth X of the bevel seat from the outer edge of the piece W. In the lower illustration, Y is the important dimension. When X and Y are right, the outer end of the plunger projects as shown. When X is too large or Y too small, the plunger end is completely inside the cap A, and when the reverse is the case, the plunger projects beyond the shoulder formed on the face of the cap. The principal advantage of these gages is that work can be carried

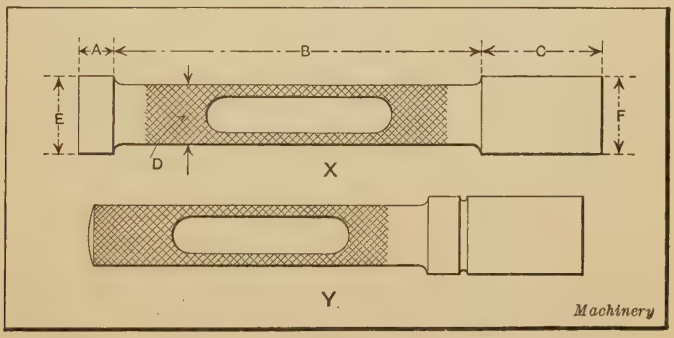


Fig. 16. Two Types of Limit Plug Gages for Small Work

on with the help of either sight or touch, and thus one sense can be used to relieve the other — a feature that will be fully appreciated only by those who are continually employed in inspection work.

Making Limit Gages. — A simple form of limit gage for testing a hole is shown at X in Fig. 16. Manufacturing standards for the principal dimensions of limit gages are slightly different in various factories, but the following system will be found satisfactory: A is always $\frac{3}{8}$ inch; B, 4 inches; C, one and one-half times the diameter of the hole to be gaged; D, $\frac{1}{16}$ inch smaller than E and F, which, of course, are determined by the work to be inspected. The portion between the ends is knurled, and two flats are milled on opposite sides.

These are for the purpose of stamping the part number and the gage sizes. Assume that the hole to be tested is $\frac{7}{8}$ inch and that a variation of 0.0005 inch is allowed — 0.0003 inch oversize and 0.0002 inch undersize. In this case, the long end of the gage should be 0.8748 inch, marked "go," while the short end is 0.8753 inch, marked "not go." The two-step form of gage is illustrated at *Y* in Fig. 15. This arrangement is employed by many tool designers because the hole can be tested without withdrawing the gage to insert the other end, which is necessary when using plugs of the type shown at *X*. This gage presents one decided objection, however, as it is impossible to tell what portion of the gage is bearing on the work in cases where the hole is slightly tapered. Notwithstanding this objection, these gages are frequently used.

The lathe work on gages is a simple operation for a toolroom lathe hand and requires no comment, except to state that the pieces should be recentered before hardening. The reason for this is that heavy roughing cuts, together with the operation of knurling, distort the centers to a certain extent, and this is sure to cause trouble in the grinding operation. To insure further accuracy, the centers should be lapped after hardening to remove the fire scale.

Grinding and Lapping Gages. — There are three kinds of materials used for wheels for gage grinding, *viz.*, emery, corundum, and artificial alumina abrasives, the last being known to the trade as "aloxite," "alundum," etc. Genuine Naxos emery will probably always be used to a certain extent on very fine work, owing to the fact that it gives a high finish. Emery wheels are comparatively slow cutting, but as gage work is an exacting operation, the extra time spent in the grinding operation is negligible when the best finish possible is desired. Corundum wheels are often used for the work in question with excellent results, as corundum is really a high-grade emery in that it contains more alumina and less impurities than the best grades of emery. In selecting corundum wheels, care must be exercised to obtain only the best quality, as poor corundum makes a very unsatisfactory wheel. Both

emery and corundum are natural products. The artificial alumina abrasives are faster cutting than the natural ones, and, for this reason and because they are readily obtained from almost any reliable mill supply house, they are extensively used for work of this kind. These wheels can be run safely at high peripheral speeds, from 6000 to 7000 feet per minute, whereas emery and corundum wheels should never, under any circumstances, be allowed to exceed 5500 feet per minute surface speed.

It is impossible to state definitely the exact grit and grade of wheel to be used for gage grinding, as the conditions vary greatly. As a general thing, however, grits 60 to 80 and grades K to N are used. In selecting aloxite wheels, it must be borne in mind that their grade scale is the reverse of the ones commonly used. As an illustration, an alundum wheel in J grade is quite soft, while an aloxite wheel in the same grade is several grades harder. Full information on this point is given in MACHINERY'S HANDBOOK.

Gage grinding differs but little from any cylindrical grinding operation, except that extreme care must be used in sizing the work to leave just the right amount for lapping; while 0.0001 inch is of little consequence in grinding, it often proves a large amount to remove by lapping in cases where the work already has a mirror-like finish. The correct amount to leave for lapping depends upon the grit and smooth cutting qualities of the wheel used. A 60 grit wheel will leave deeper marks in the work than a 70 or 80 grit wheel, and a wheel that is properly dressed leaves a smoother finish than one that has simply been roughed up. In general, from 0.0002 to 0.0003 inch is sufficient allowance for lapping.

It is imperative that gages be lapped after grinding, no matter what kind of wheel is used; otherwise the friction between the work and the gage will soon wear the latter slightly undersize. This is because any piece of ground work (no matter how fine a wheel has been used) always shows innumerable scores and high spots when examined under a microscope. The high portions would soon wear away after the

gage were put in use, and the object of lapping is to wear the high spots away and bring the gage to a mirror-like finish, which will resist wear for a comparatively long time. There are several methods used for lapping cylindrical gages, the most crude and unsatisfactory being to polish them with fine emery cloth. This is poor practice, and it is never resorted to by the toolmaker who understands his business. Another method is to use a wooden clamp not unlike the polishing clamps used for finishing shafting some years ago. Lard oil and rouge are used, and good results are possible in the hands of an expert workman, as the rouge has not enough abrasive action to remove much more than the actual high spots. Great care must be taken while grinding to leave just the correct

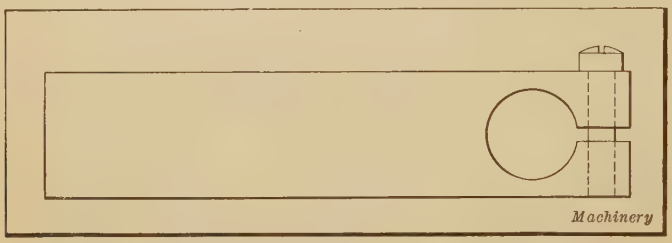


Fig. 17. Form of Lap used for Lapping Plug Gages

amount for lapping if this method is employed, because, after the actual high spots are removed, the rouge cuts the finished surface very slowly.

The most practical method is to use a cast-iron lap and carefully washed flour emery mixed with lard oil. A lap of this kind can be easily made as shown in Fig. 17. It consists of any convenient piece of open-grained gray iron with a hole bored in one end to receive the work. The extra length serves as a handle. Laps of this kind should be split and provided with a screw for taking up wear, as a lap should fit the piece snugly in order to do good work. The lapping operation should not be hurried unduly, as this procedure will sometimes result in an undersized gage; and while there is always a chance of saving a gage that is a little oversize, one that is undersize is an absolute loss. The work should be washed in gasoline

before calipering and then cooled in water that has stood in a bucket long enough to acquire the temperature of the room through radiation; otherwise a very slight error will be apparent, even though the work may be done by a competent workman.

Gages made by the above methods are not absolutely accurate when compared with the famous Johansson gages. However, they are accurate enough for regular commercial work, and as they can be made at low cost, no great expense is involved when they go to the scrap box after being worn to the point of uselessness.

Electroplating Gages. — One of the serious problems of interchangeable manufacture is the maintenance of gages. Obviously a gage, whether external or internal, begins to wear with the first piece gaged, and wear is continuous with use. The question is: what limits shall be put on gage wear which, when exceeded, will require that they be discarded or returned to the tool-room for readjustment? If the limits established are very narrow, the cost of inspecting gages and restoring them to their original condition will be very heavy; and on the other hand, if the limits are wide, the gages will eventually become so worn that their usefulness as a means for maintaining standards will be lost.

The electroplating process presents a means by which gages may be restored to their original condition at a minimum cost. The process may be used also as a check on the wear by which any user will be appraised of the fact that the gage has worn below standard. Suppose a hardened steel plug gage is electroplated with a copper film 0.00005 inch thick. The total increase in diameter of the plug gage is then 0.0001 inch. Suppose this is established as a limit of wear of the plug gage. Then the limit approximately is reached when the copper film is worn through and the hardened steel becomes visible. The restoration of the gage to the original size is merely a matter of suspending the gage in the electroplating bath a certain number of minutes, the time depending upon the thickness to be deposited, the voltage, and other factors affecting the

deposition of the copper. All these factors may be accurately determined and the electroplating battery may thus be employed as an accurate means of building up to the exact size.

The objection to this system that doubtless will be urged is that copper is a soft material and wears rapidly, but a *thin* film of copper deposited on hardened steel wears comparatively slowly, as experience has demonstrated. The method is one that is worthy of the earnest attention of gage-makers, toolmakers, and others concerned with the manufacture, use, and maintenance of gages used in interchangeable manufacture.

CHAPTER IV

PROFILE GAGES

MANY different types of gages have been devised for testing surfaces, measuring shoulder distances, and determining the amount of eccentricity or the truth of cylindrical parts. The ordinary plug or snap gages, while extensively used in interchangeable manufacture, do not indicate the amount of error that exists in the part; they simply determine whether the parts are small or large. The solid profile gage has a similar disadvantage in that it does not show how much the profile of the part is out; and for such purposes, properly designed indicating gages must be used.

Templet and Profile Gages. — Templet and profile gages, which are generally made from sheet steel, are used for measuring shoulder distances, profiles of irregular shape, and angles. These gages are usually comparatively cheap to make, and in most cases are sufficiently accurate for the work they are intended to inspect. Take, for instance, the gaging of the overall length of a shaft as shown at *A* and *B* in Fig. 1. For work of this kind, a templet gage can be satisfactorily employed. It should be made as shown at *B*, however, rather than as shown at *A*. The reason for this is that there is less liability of the operator's springing the gage by forcing the work into it. In the type shown at *B*, work which will enter the "go" end of the templet cannot be forced as easily into the "not go" size as in the type shown at *A*. On the other hand, the type shown at *A*, when used with care, has the advantage that there is less liability of the operator's fitting the work to the "not go" end, instead of to the "go" end.

Another case where a combination gage can be used with satisfactory results is shown at *C*. In this case, the templet controls the shape of the head as well as its thickness. Al-

though more than one point is being tested by this gage, the work is not usually required to be very accurate, and a templet gage of this kind is satisfactory. Reference to this illustration will show that the work on the "go" end should bear all over on the gage, whereas on the "not go" end it will not go completely down into the slot. Where the thickness of the head from a shoulder is the only point that is necessary to hold accurate, a gage of the swinging arm type is much more satis-

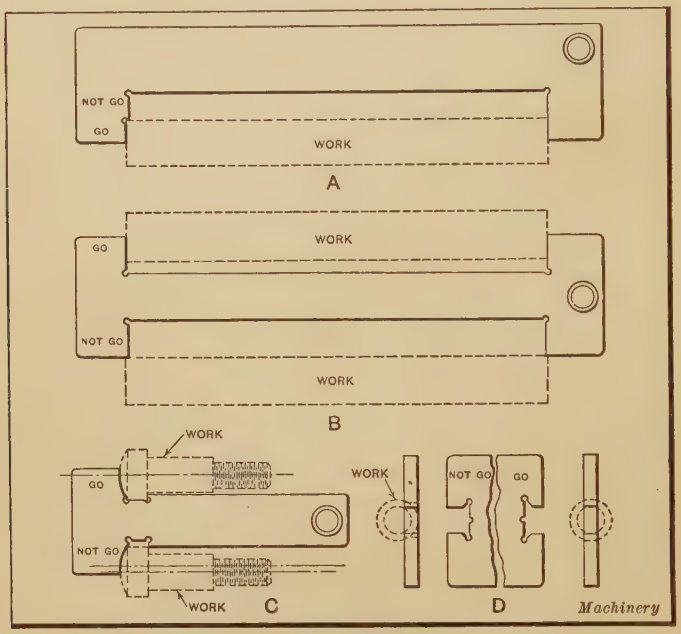


Fig. 1. Diagram illustrating Application of Templet and Profile Gages to Simple Parts

factory than the templet form. This matter will be dealt with more fully later.

A simple templet for testing work of angular shape is shown at *D* in Fig. 1. In this case, the templet is used to test the diameter of the screw and the thickness and angle of the head. For accurate work, too many points are being tested, but for the average run of flat-head screws, a templet gage of this type gives satisfactory results. When greater accuracy is required

on work of this shape, a progressive gage covering each individual point would be more satisfactory.

Another application of the templet system of gaging in the production of shoulder shafts is shown at *A*, *B*, and *C* in Fig. 2. At *A* is shown a templet which is used for controlling the shoulders of one end of the shaft — for the first operation; at *B* is shown the gage for controlling the length of the shoulders on the opposite end of the shaft — for the second operation; at *C* is shown the gage used by the inspector for covering the entire length of the shaft. It is much more satisfactory to supply the workman with a gage of the type shown at *B* for the second operation than it is to supply him with the type shown at *C*. The latter should only be used by the inspector, for the reason that, as long as the work goes in this gage, it is satisfactory; if it does not go in the gage, it is unsatisfactory. This gage is, therefore, given as wide a tolerance as possible. For the second operation, as shown at *B*, the shoulder *a* would be controlled by the end *b* of the gage. When the length of certain shoulders is required to be accurate, this system of inspection is not recommended, and a limit gage (to be described later) should be employed.

A form of templet gage which is used extensively in the manufacture of engine lathes and other similar machine tools is shown at *D*. This gage is used for testing the angle on the ways of the lathe on which the carriage operates, and at the same time for determining if the distance between the V's is correct. Extremely accurate results are obtained by means of this templet gage in the hands of an experienced operator. Either a feeler or thin piece of tissue paper is used to test both the angle and the distance of the ways. When templet gages of this shape are accurately made and carefully applied, satisfactory results are obtained.

Another application of the templet system for testing the arc of a circle is shown at *E* and *F*. In this case, the part being tested is a ring for a ball thrust bearing. At *E*, the curve on the lower surface is being tested with a templet; at *F*, two knife-edge shaped disks are used to test the center distance

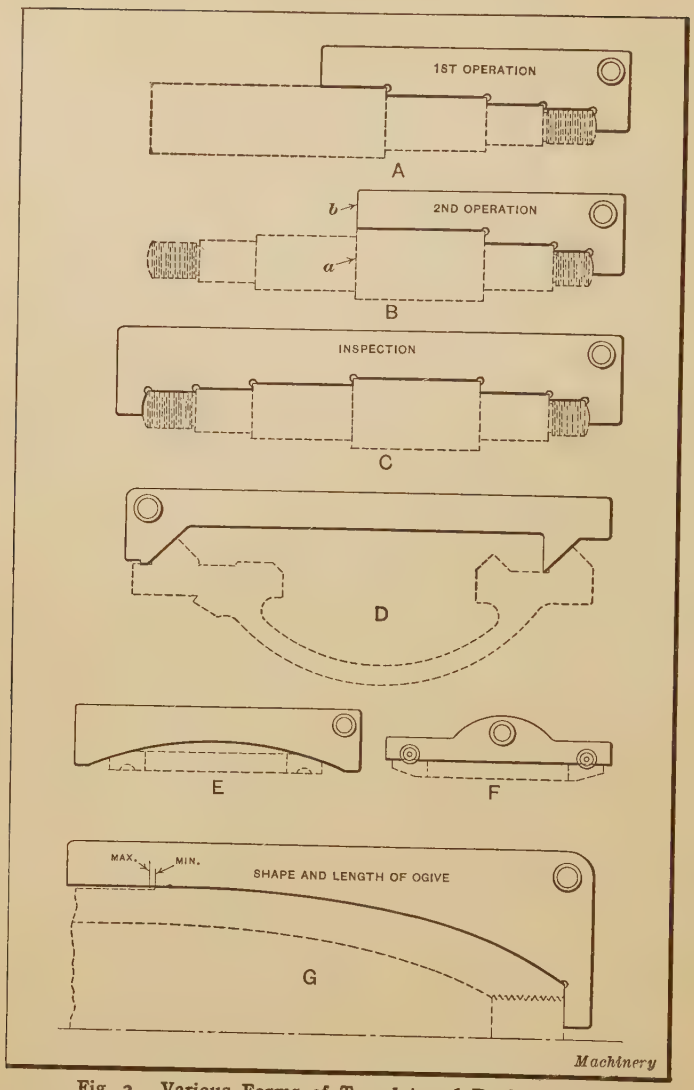


Fig. 2. Various Forms of Templet and Profile Gages

of the raceway. Inaccuracy of the work is indicated by light showing between the gage and the work, but the gage does not determine how much the work varies from the size or shape required. For this purpose, an indicating gage should be used in preference to the templet form.

An application of the templet form of gage to curve and length measurements is shown at *G*. In this case, the piece being tested is the ogive or nose end of a shell. Two points are tested — one is the shape of the nose, and the other the location of the "bourrelet" or the cylindrical portion on the head end of the shell which rests in the gun and is formed by the termination of the ogive and the beginning of the reduction or recess on the body. In this case, the templet is so made that it can be used in connection with the limit system of manufacture, having two lines on it, one indicating the mini-

Fig. 3. Built-up Type of Profile Gage for Shrapnel Shells

mum and the other the maximum position of the bourrelet. The position desired is midway between these two points.

Built-up Templet Gage. — A built-up templet or profile gage which was made to supersede one made from $\frac{5}{32}$-inch sheet steel is shown in Fig. 3. This is used for the final inspection on a 3-inch Russian shrapnel shell. Work which passes through it is satisfactory, while work which will not pass through it is rejected. The gage is provided with legs which support the outline plates at a distance from the surface plate equal to the radius of the shell. It consists of a base made from machine steel, $\frac{5}{16}$ inch thick, with a clearance hole of approximately rectangular shape. Onto one side of this baseplate are screwed

and doweled four strips of hardened tool steel which form the gage proper. It is also provided with six bumper pieces attached to the lower side of the gage body. These bumpers are tapered back so as to form a bell-mouth and locate the shell approximately as it is about to enter the gage. When the profile of the gage wears, any one of the four strips is moved inward, correctly placed, and then the dowel holes are re-reamed for a slightly larger dowel-pin.

Limit System applied to the Gaging of Shoulder Distances. — Fig. 4 shows a gaging device for inspecting shoulder shafts, that works on the limit principle. This gage consists princi-

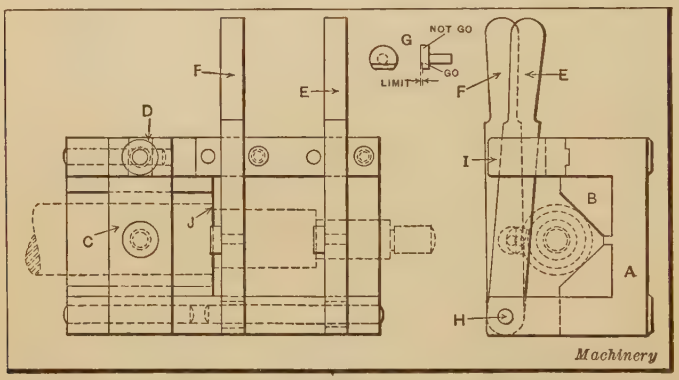


Fig. 4. Diagram illustrating Application of Limit System to gaging of Shoulder Shafts

pally of a base *A* carrying a V-block *B* in which the work is clamped by means of a strap *C* and the swinging bolt *D*. The relative locations of the two shoulders are determined by two levers *E* and *F*, respectively, which carry limit buttons of the form shown at *G*. These levers are fulcrumed on one side of the gage on a pin *H*, and fit in slots in the hardened, ground and lapped block *I*. In using this gage, the work is put into the V-block, and the operator holds it with one hand while he moves down lever *F* with the other hand until the shoulder *J* on the work is in contact with the "go" limit on the plug held in lever *F*. The swinging strap *C* is then clamped by means of the bolt *D*, holding the work rigidly in position. The

operator then brings down lever *E* and tests the location of the second shoulder in relation to the first. In this way, shoulder shafts can be held within very close limits when necessary. If the limits were very close, it would be possible for the operator to spring the "not go" surface on the plugs past the work, but as in practically all gaging devices the sense of touch is necessary, there is no reason why an operator should apply greater force when he has the leverage to do so than is necessary to bring the measuring surfaces on the gage in contact with the work.

Progressive or Combination Gages. — Gages which are used for inspecting a number of dimensions on one particular piece are generally termed "combination" or "progressive" gages.

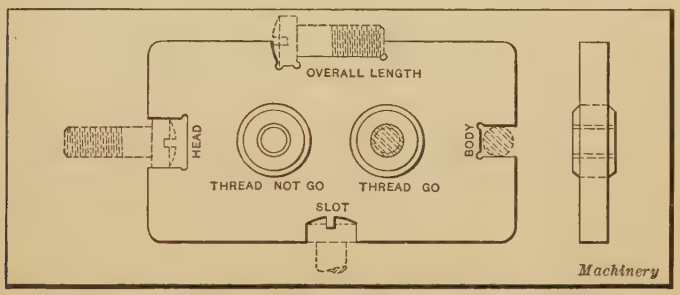


Fig. 5. Progressive Type of Templet Gage for Inspecting Fillister-head Screws

One type of gage which illustrates this principle is shown in Fig. 5. In this case, the gage is used for testing the body, over-all length, head, slot, and thread of a fillister-head screw. The only part for which limits are provided is the thread. This is tested in a "go" and "not go" threaded bushing inserted in the templet. Gages of this kind have one marked disadvantage in that, as soon as any one position or point on the gage becomes worn, with the exception of the threaded bushings, the entire gage has to be discarded. For screws and other parts which do not require to be extremely accurate, however, this gage gives fairly good results and is quite extensively employed. When the work demands greater accuracy, separate gages should be provided for testing each dimen-

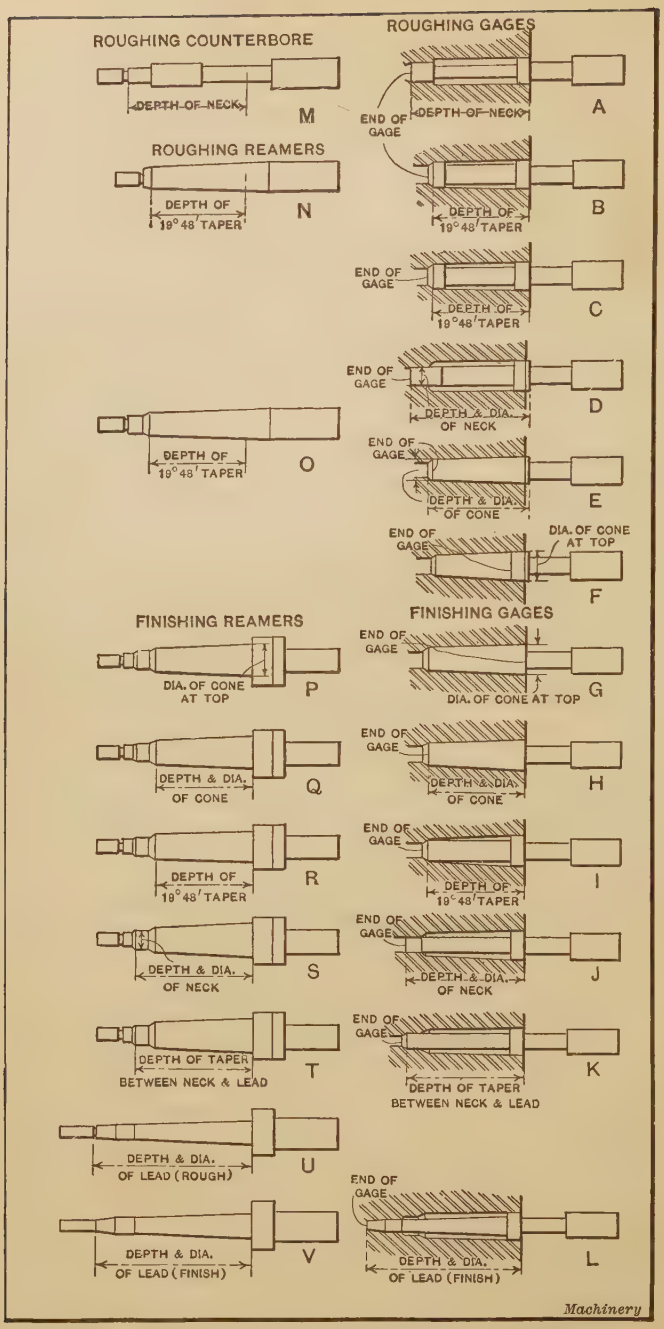


Fig. 6. Tools and Gages used in machining Cartridge Chamber

sion. This necessitates a more costly gage-set, but, when very accurate work is essential, the cost of upkeep is less.

Progressive Gaging of Cartridge Chamber in Rifle Barrel. — Another example which could come under the class of progressive gaging is shown in Fig. 6. This illustrates the tools and gages used in machining and inspecting the cartridge chamber of a rifle barrel. It is not an easy problem to produce a perfectly chambered rifle, and it requires both a high degree of workmanship and a complete and practical gaging system. The chart shown in Fig. 6 illustrates the counterbore, roughing and finishing reamers, and also the roughing and finishing gages used for machining and gaging the chamber in a 0.303 Ross military rifle. At first glance, it would appear that there is an excess of gages used; however, this is not the case, as the following explanation will show.

The manner in which these tools and gages are used is as follows: The chamber is first roughed out with a counterbore *M* and then gaged at the mouth and in the bore with the gage *A*, to see that the counterbored hole is of the exact diameter and is concentric with the bore in the barrel. (It is necessary that this point be carefully determined, because any eccentricity would be difficult to correct in the following operations.) The chamber is now reamed with a roughing reamer *N* and gaged with the gage *B*. The reamer shown at *O* is then used for finish-reaming the taper and neck and also for roughing the cone diameter. It would be impossible to make one gage so that it would act as a detector for all the various diameters finished by this reamer, and this inspection operation requires the use of gages *C*, *D*, *E*, and *F*, the limit lines on which should come flush with the end of the barrel when the reamer is of the correct size and is inserted to the proper depth.

This finishes the rough-reaming and respective gaging operations, after which every part of the chamber is again finished with finishing reamers and gaged. The operations accomplished by the reamers *P* to *T*, inclusive, are inspected with the gages *G* to *K*, inclusive, which are made so that a slight change in diameter can be noted by shaking the gage. The

reamers *U* and *V* and the gage *L* are used for machining and gaging the lead to the rifling grooves. The lead may be briefly defined as the conical funnel which leads from the chamber to the bore. If the chamber ended abruptly at the beginning of the rifling grooves in the bore of the barrel, the sharp ends of the lands would cut strips out of the nickel jacket case of the bullet. The lead must be concentric with the chamber and bore, or else the bullet will be likely to wobble or "tumble" after it leaves the muzzle. The progressive system of gaging is necessary to obtain the desired accuracy.

Progressive Gaging of Screw Machine Products. — The two previous examples of progressive or combination gages illus-

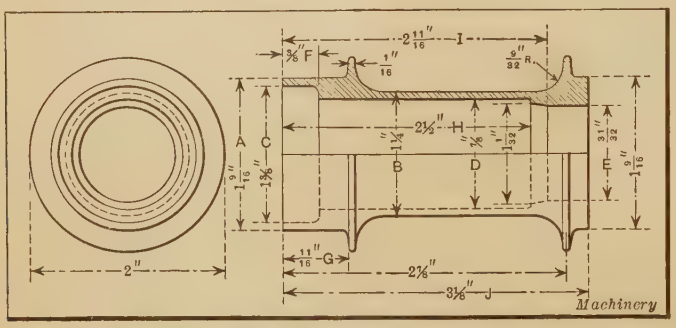


Fig. 7. Bicycle Wheel Hub which can be successfully inspected by Method shown in Fig. 8

trate the ways in which it is necessary to apply the gage to the work. When a considerable number of dimensions on the work require gaging, and especially when the work is quite large, it is necessary to have a large gage of the type shown in Fig. 5, which is rather bulky to handle. On the other hand, in gaging work like the cartridge chamber in a rifle barrel, shown in Fig. 6, where a large number of gages are required, it necessitates lifting up and putting down each gage once for each barrel inspected. A method of progressive gaging which can be applied with particularly satisfactory results to screw machine products, such as the bicycle wheel hub shown in Fig. 7, is illustrated diagrammatically in Fig. 8. Here the gage consists of a large cast-iron plate, the top surface of which

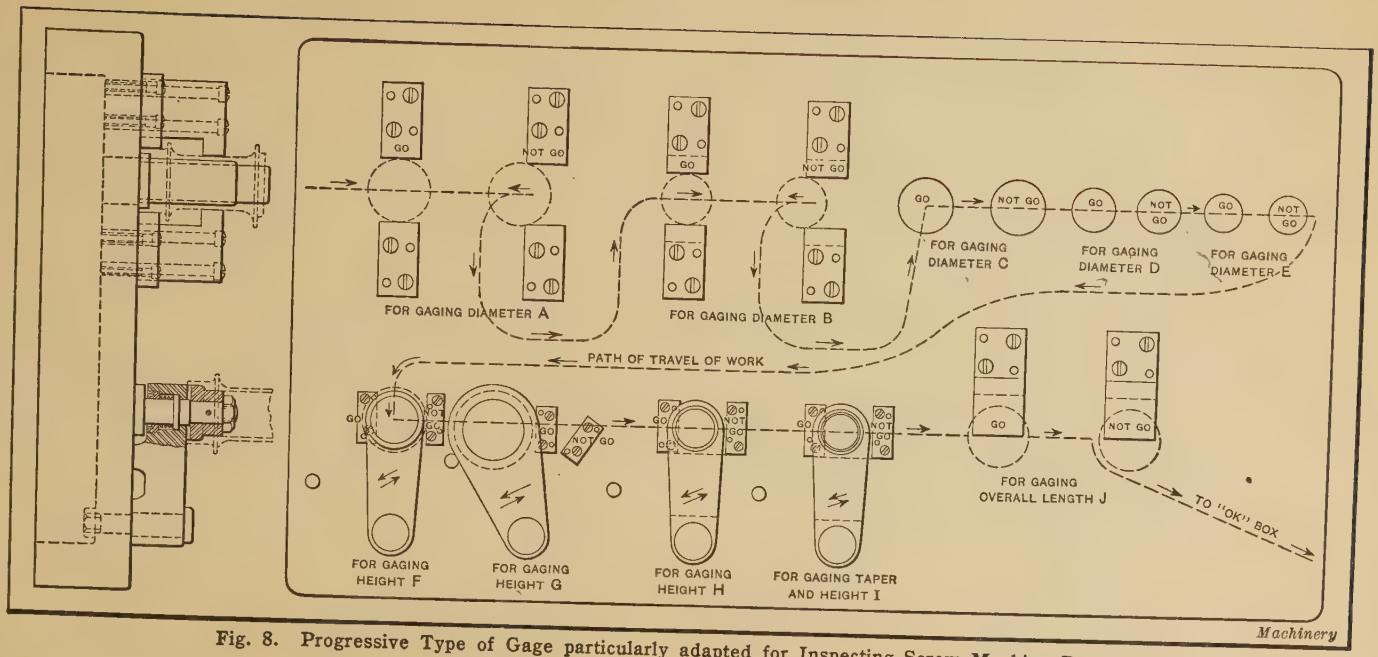


Fig. 8. Progressive Type of Gage particularly adapted for Inspecting Screw Machine Products

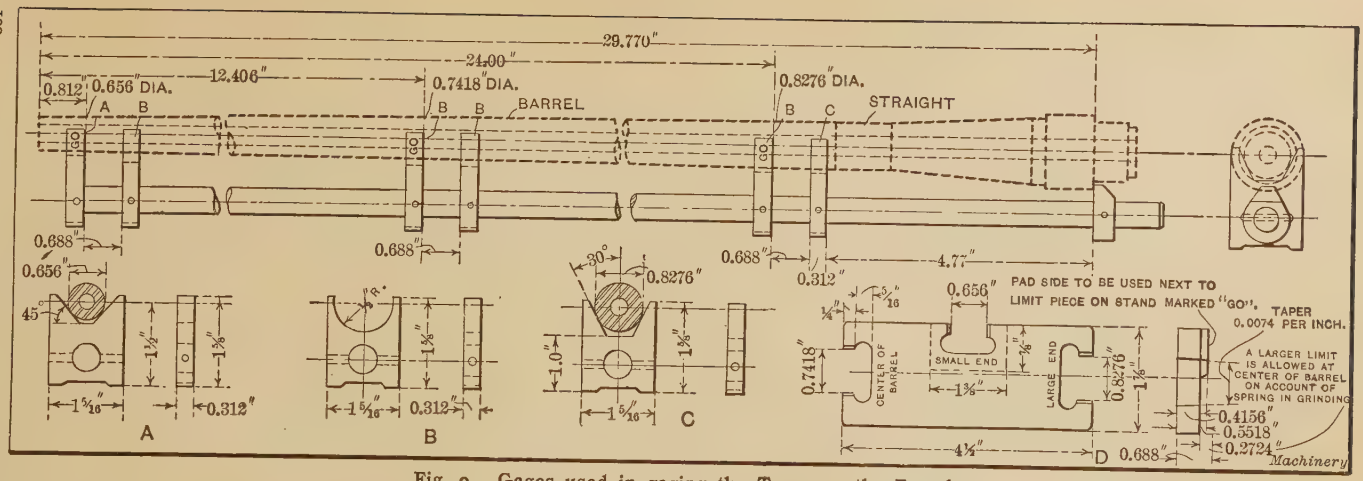


Fig. 9. Gages used in gaging the Taper on the Barrel

is carefully machined and preferably finished by grinding. Various types of gaging points, plugs, swinging members, etc., are attached to the top surface of this plate.

Diameters *A*, *B*, *C*, *D*, and *E*, and heights *F*, *G*, *H*, *I*, and *J*, Fig. 7, can be gaged in a satisfactory manner as shown in Fig. 8. For instance, for gaging the diameters *A* and *B*, four sets (two each) of carefully hardened and ground blocks are fastened to the plate, the first two blocks in each set being known as the "go" sizes, through which satisfactory work will pass, and the second set as the "not go" sizes, through which work of the required size will not pass. For the gaging of the hole diameters *C*, *D*, and *E*, ordi-

nary plugs are fastened to the surface plate, one being made to go into the hole and the other not to go in. For gaging the depth of the counterbore *F*, the work is placed on a spring plug, as indicated in the section of the end view of the fixture. Here the lower face of the work rests on a swinging arm, and in doing so forces down the spring-operated plunger. When the work is correct, this slips over the "go" block, but will not go over the "not go" block. For gaging the height of the shoulder *G*, the work is let down into the swinging arm instead of on a plug, and the work itself, instead of a hardened plug, passes over the "go" block when correct. For the gaging of the height *H*, a scheme similar to that used for gaging the height *F* is adopted. For gaging the height *I* and also the taper, the plug is made with a tapered shoulder and the work rests on this taper and is guided near the bottom only by a shoulder on the stud. In this way, the height and diameter of the taper are controlled. For the over-all length, the work is simply passed under limit height blocks.

The facility with which work can be handled in this manner is remarkable. For instance, an experienced operator could gage all the ten dimensions noted on this particular part in from eight to ten seconds, and when the tolerances on the work are from 0.003 to 0.005 inch, this type of gaging is sufficiently accurate. It is especially advantageous for the inspection of work which, after being turned out on the screw machine or turret lathe, is heat-treated and then must be finished by grinding. The grinding tolerances can be provided for on this rough inspection gage. Where a greater refinement is necessary on the work, accurate gages can be fastened at frequent intervals to the top surface of the plate and the gaging of the parts done in the same way as outlined. For instance, it would be a simple problem to attach any type of indicating gage to a plate in this manner and thus bring all the gages for any certain piece together, so as to eliminate the necessity of lifting the gage to the work or moving from one place to the other along a bench. This principle works out very successfully when the work is comparatively light, clean, and free from burrs.

In designing a gaging fixture of this type, it is desirable to keep the work on the surface plate as much as possible. This feature has been adopted because it is simpler to slide the piece along the plate than it is to keep lifting it up from point to point. Of course, there are cases where this is impossible, but the aim in view should be to eliminate, as far as possible, any feature which would tend to tire the inspector. Another advantage of this type of gage is that girls can be satisfactorily employed for the work.

Gaging the Taper on a Rifle Barrel. — After the barrel of the Ross rifle has been finish-ground externally, the taper,

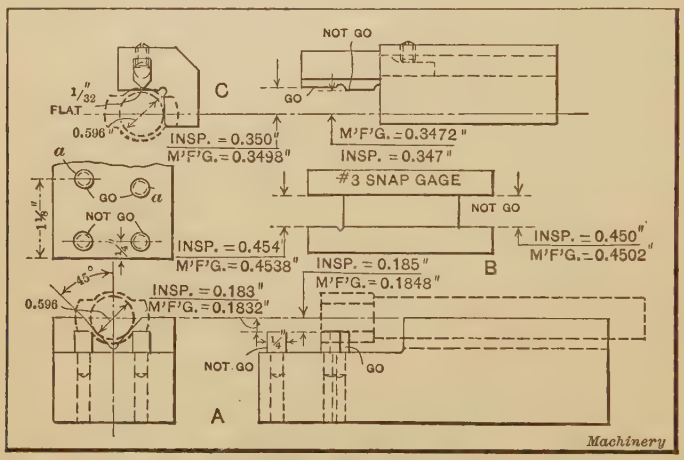


Fig. 10. Snap and Stand Gages used in gaging the Head of the Bolt after Form Milling

which is 0.0074 inch per inch, is inspected in the gage shown in Fig. 9. The barrel is held in the supports *A*, *B*, and *C*, which act as a stand, and also as limit "points," snap gage *D* working in between them. The limit blocks are all placed the same distance apart — 0.688 inch — and as a greater limit is necessary at the center of the barrel on account of spring in grinding, the part of the gage for the muzzle end is padded on one side to reduce the limit. The limit allowed at the muzzle end is 0.001 inch, the padded side of the gage being held against the "go" block *A*. The limit allowed in the center

and large end of the barrel is 0.002 inch; the gage *D* for these parts not being padded, it has a greater movement between the limit blocks. The barrel is gaged at the muzzle and near the breech end at the points where the front and rear sight bases are located, so that the sight bases will be in the same relative positions on each barrel.

Gaging the Bolt of a Ross Rifle. — After the head of the bolt is form-milled, it is gaged in the gages shown in Fig. 10. The gage shown at *A* locates the position of the faces of the lugs by means of pins driven into the V-block in which the bolt

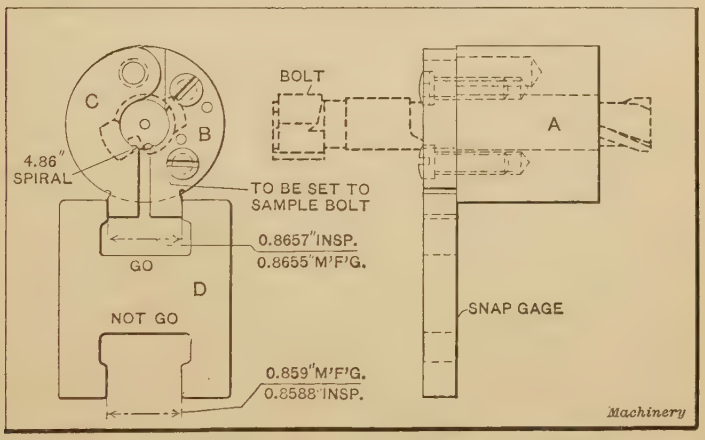


Fig. 11. Snap and Swinging Gage used in gaging the Width of the Spiral Ribs on the Bolt

is placed. A point worthy of attention in this gage is the staggered position of the $\frac{1}{4}$-inch pins *a*, shown in the plan view. Locating the pins in this manner facilitates the inspection of the work. The thickness of the lugs is tested by means of the standard snap gage shown at *B*, and the height of the shoulder on the bolt head is gaged in the gage shown at *C*. This latter gage consists of a plain block in which the limit gage, provided with "go" and "not go" bosses is held by a screw.

An interesting gage for taking a difficult measurement is shown in Fig. 11. This gage is used for inspecting the width of the spiral ribs on the bolt. It consists of a block *A*, to

which is held a rigid jaw *B* and a swinging jaw *C*. The limit snap gage *D*, which is used to take the measurement, fits over the ground ends of the jaws *B* and *C*. That part of the jaws

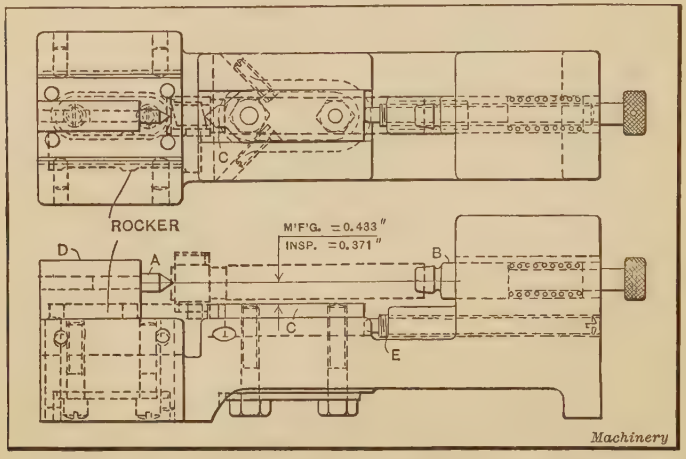


Fig. 12. Stand and Rocker used in gaging the Locking Cam at the Rear of the Bolt Head

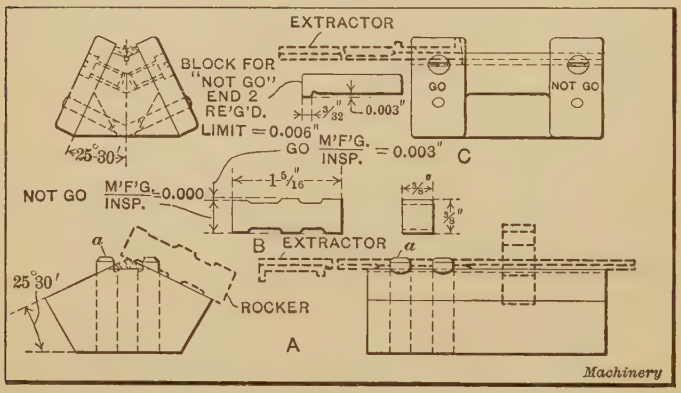


Fig. 13. Gages used in gaging the Thickness and Width of the Extractor

which comes in contact with the spiral ribs on the bolt is cut to fit the spiral rib, which makes one turn in 4.86 inches.

Another interesting use of a so-called "rocker gage" is shown in Fig. 12. This gage is used to gage the position of the locking cam on the rear of the bolt head. The bolt is placed on the

center *A* and the spring-actuated plug *B*, and is rotated until the cam comes in contact with the 90-degree pointed block *C*. The rocker is then used from the sides of the block *D*, holding the center *A*. The pointed block *C* is adjusted by means of the screw *E* and is set to a master bolt. The block holding the center *A* is also made adjustable and is set in the desired position.

Gaging the Extractor of a Ross Rifle. — The extractor, which is used for removing the exploded cartridge from the chamber in the barrel, is beveled on the back and fits in a groove cut in the bolt sleeve. The thickness of this extractor and the angles of inclination of its back are gaged in the block and rocker gage shown at *A* in Fig. 13. The extractor is located between four pins *a*, and the rocker shown at *B* is applied as illustrated. The tapered sides and width of the extractor are gaged in the block gage shown at *C*. This gage, instead of having a rocker, consists of a plain block beveled to the required shape and to which four blocks are fastened, two on each end. The blocks on one end are ground so that a perfect extractor will not enter, while the blocks on the other end are ground so that a perfect extractor will enter.

CHAPTER V

INDICATING GAGES

INDICATING gages may be divided into three distinct classes — those employing the sense of touch, those depending upon sight, and those upon hearing. These three classes are subject to considerable subdivision, but the main principles involved remain the same. Gages which employ the sense of touch are known as "flush-pin" or "feeler" gages; those employing the sense of sight are "multiplying lever" or "dial indicating and micrometer" gages; while those depending upon the sense of hearing produce some sound when the part is of the required size, tension, etc. A common type of gage employing this principle is an electric gage, in which a bell is rung if the piece is of the right size.

Indicating Gages Employing Sense of Touch. — The most common form of indicating gage employing the sense of touch is the flush-pin type of gage shown in Fig. 1. Reference to this illustration will show that the gage consists of a base *A* carrying a bracket *B* and a measuring spindle or flush-pin *C*. The forward end of bracket *B* is machined to circular shape and is provided on its top surface with a step equal in height to the permissible tolerance on the work — in this case, 0.005 inch. The lower end of spindle *C* is made sufficiently large to seat on the counterbored seat in the work. The distance from the lower face of this enlarged portion to the reduced shoulder on the spindle is such that, when work within the required limits is being tested, the counterbored seat in the work will lift up the spindle sufficiently to bring the shoulder on spindle *C* either flush with the upper or lower shoulder on the boss on bracket *B* or midway between these points. The most desirable condition is to have the shoulder on the flush-pin midway between the plus and minus limits. While 0.005

inch can be seen with the naked eye, it can be detected more rapidly with the finger, so that this type of gage is known as the "flush-pin" or "touch-type" of gage. The sense of touch is much more accurate than most people appreciate, and, as a matter of fact, it is possible to detect differences as small as 0.0003 inch.

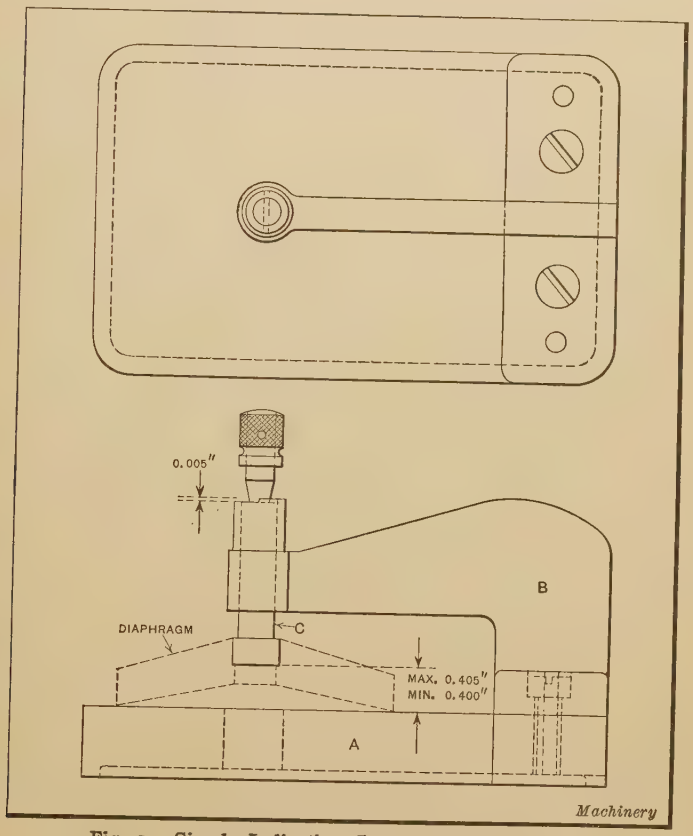


Fig. 1. Simple Indicating Gage of Flush-pin Type

Another type of gage which depends for its accuracy upon the sense of touch is shown in Fig. 2. This gage is used for testing the position of the milled groove on the under side of a bolt sleeve for a military rifle. The sleeve proper is held in a fixture on hardened and ground plugs *A*, *B*, and *C*. Plug

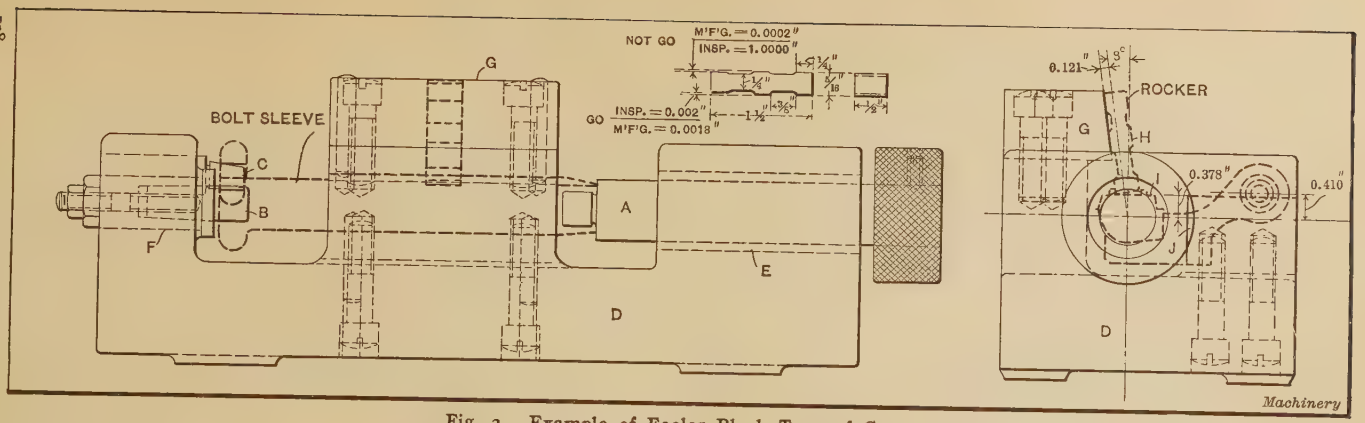


Fig. 2. Example of Feeler Block Type of Gage

A is provided with a knurled head and is made a good fit in the hardened and ground sleeve *E*. Plug *B* is made with a tapered shank and is held in a hardened and ground taper sleeve by a stud and nut as shown. Sleeve *F* is provided with a shoulder which abuts against the cast-iron boss on the base *D*. Plug *C* is tapered, fitting a hole in the handle of the bolt sleeve, and is driven into reamed holes in the boss on the casting. The inspection is done by means of what is known as a "rocker block," which is made from steel, hardened, ground and lapped. This block works on the hardened and ground block *G*, fastened by screws and dowels to the casting *D*, which acts as a measuring surface for the rocker gage. The rocker gage or block *H* has three bosses on the sides, two of the bosses on each side acting as supports, while the other boss is made lower than the supporting bosses an amount equal to the tolerance allowed on

the work. This gage is also used for testing the height of the shoulder *I* on the bolt sleeve, the rocker *H* being located on the hardened and ground block *J* in a manner similar to that previously described. In applying this rocker, it is laid on the hardened and ground surfaces of the fixture and then moved forward to see if it will pass over the work. The "go" end passes over the work and the "not go" does not, if the work is satisfactory.

A flush-pin gage which is used for determining the depth of a slot in a rifle part is shown in Fig. 3. In this case, the slot

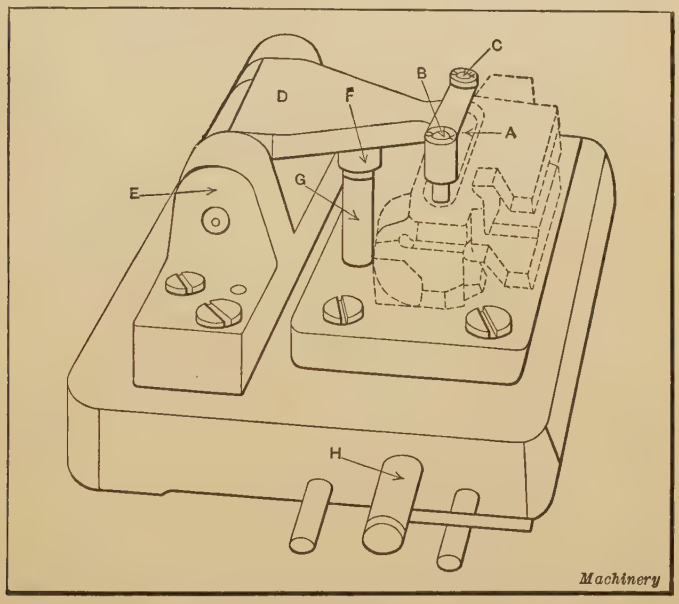


Fig. 3. Flush-pin Type of Gage employing a Swinging Arm

A in the part is inspected by two flush-pins *B* and *C* which are held in a swinging member *D* in the bracket *E*. Swinging member *D* carries a hardened and ground locating plug *F* which, when in position for gaging, comes in contact with a hardened and ground plug *G* in the base of the gage. These two pins insure that the swinging member is always brought to the same position. Then, by feeling the height of the flush-pins in the swinging member, the depth of the slot is tested;

the piece being gaged is held on the base of the gage on dowel-pins, and is ejected after being tested by means of handle *H* through an eccentric movement.

Indicating Sight Gages. — Indicating gages employing the sense of sight may be roughly divided into five general classes, *viz.*, those of the multiplying lever type; those of the needle and dial indicating type; those employing a micrometer screw; those using the cross-hair microscope in connection with the micrometer screw; and those employing the reflection of light rays.

Multiplying Lever Type of Gage. — The average gage constructed on the multiplying lever principle, when used for fine measurements, has several disadvantages, chief among which is the weight of the moving parts. This can be largely compensated for, however, by the correct proportioning and arrangement of the levers, so as to balance the weight of the various parts. When set by a master and used simply as a means of comparison, the multiplying lever indicating gage may be satisfactorily employed on a large range of work.

Needle and Dial Gage. — Needle and dial indicating gages are made in several different types, the type employing a train of gears for obtaining the multiplying movements of the needle being the most common. There are several objections to this form of indicator, which may be summarized as follows: 1. Backlash in the gears due to wear. 2. Fluctuation of the indicating needle. 3. Lack of brake or dashpot to eliminate fluctuation of the needle. 4. Unequal wear of moving parts — especially of the gears.

As a rule, a gage of this type is used on one size of work for weeks at a time, with the result that those portions of the gears constantly in mesh wear much more rapidly than the remaining or unused portions. This makes the gage inaccurate for anything but comparative measurements, and it must be corrected and set frequently by means of master blocks. The fluctuation of the indicating needle is one of the most annoying features of this type of gage. It is due to the unbalanced action of the parts and to backlash in the gears.

For rapid inspection, a gage in which the needle continually fluctuates is of little or no value, and it has been suggested by inspectors that a brake or dashpot be provided in order to eliminate this objectionable feature. The computing scale is a good example of a measuring instrument employing a dashpot, and a similar arrangement adapted to an indicating gage of the needle type would greatly increase its usefulness. Unequal wear of the moving parts is also a factor which should receive careful consideration. The number of parts employed in a gage of this type should be reduced to a minimum, so as not only to simplify its construction, but also to decrease the chances for wear and consequent inaccuracy. As will be explained later, other types of needle indicating gages have been devised to which the objections mentioned do not apply.

Micrometer Gages. — The micrometer caliper is a type of gage which depends both upon sight and touch for its accuracy. The micrometer screw has been applied to many different types of gages, and, as will be subsequently described, this type of gage has certain advantages for work which cannot be measured by any other means, or which is inaccessible to a regular snap or plug gage. The micrometer screw furnishes an accurate means of inspecting work, but it is necessary that a gage of this type be frequently checked with a reference gage to see that the screw is not worn and that the measuring points of the gage are parallel with each other.

Microscope Gages. — The cross-hair microscope in connection with the micrometer screw provides one of the most accurate methods of inspecting small articles, such as thread gages, ball races, fly-cutters, etc. The number of industries, however, employing this instrument is not nearly as great as its adaptability would seem to warrant. For many classes of work, the accuracy which can be obtained by this method is much greater than that which would ordinarily be required.

Reflection of Light Rays. — For extremely accurate work, gages employing the reflection of light rays have been developed. These, however, are not extensively used and have only been adopted where extreme accuracy is necessary and where a large

number of parts must be inspected in a certain time. The light ray presents a rapid means of ascertaining inaccuracies as small as 0.0001 inch, which can be read off from a screen with great rapidity. For such work, a highly developed inspection and gaging system is necessary.

Multiplying Lever Indicating Gage. — Multiplying lever indicating gages are made in so many types that it is impossible

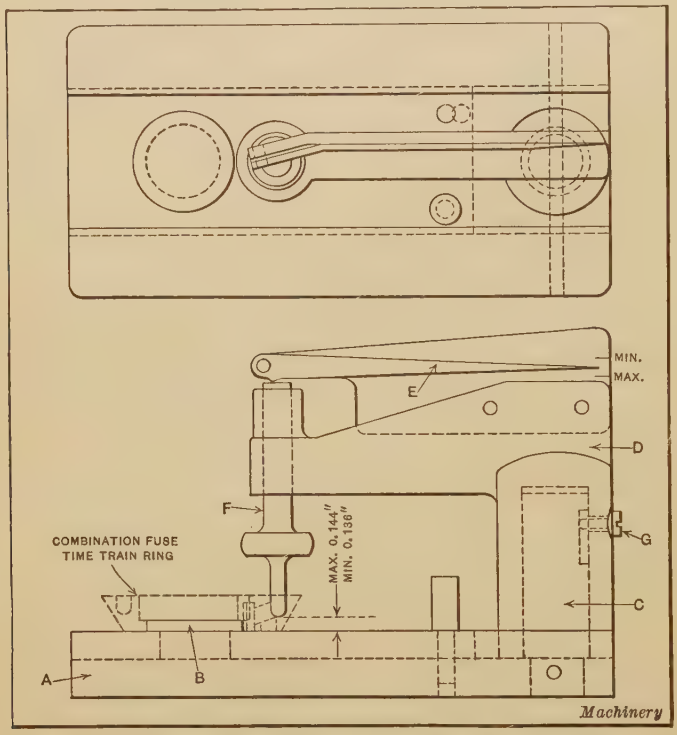


Fig. 4. Common Form of Multiplying Lever Indicating Gage

to cover them all with detailed descriptions. An endeavor will be made, however, to deal with their principles of construction and operation. Fig. 4 shows a common form of multiplying lever indicating gage which, in this case, is used for testing the depth of the powder groove in the ring for a combination time and percussion fuse. The gage consists of a base *A* provided with a dovetail groove in which the work-

holder *B* is free to slide. A stud *C* in the rear end of the base acts as a pivot for the swinging arm *D*, the latter carrying the indicating needle *E* and plunger *F*. The fulcrum point of pointer *E* is so placed in relation to the knife-edge which comes in contact with plunger *F* that a multiplying movement of 25 to 1 is obtained. To insert the work under the measuring plunger, arm *D* is raised, its movement being stopped by the fillister-head screw *G*.

There are several objections to this gage. In the first place, the necessity of raising arm *D* to insert the work makes it possible for dirt to collect under the seat, and thus cause the gage to read incorrectly. It is also unsuited for very accurate

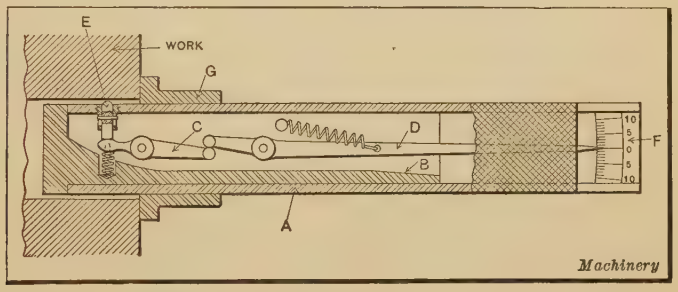


Fig. 5. Multiplying Lever Indicating Gage for Internal Work

work, because of the small multiplying movement of the lever, which gives only 0.025 inch between each graduation on the scale for each 0.001 inch variation in the work.

Multiplying Lever Gage for Internal Work. — Another multiplying lever indicating gage, which is used for measuring internal work and is provided with two multiplying levers, is shown in Fig. 5. Reference to this illustration will show that the gage consists of a sleeve *A*, inside of which is fitted a member *B* milled out to receive the two multiplying levers *C* and *D*. The gage is provided with three contact points, only one of which — point *E* — is movable, the other two being adjustably held in the sleeve *A*. A coil spring, as shown, keeps the forward end of lever *C* in contact with the lower end of contact point *E* and another spring keeps the forward end of lever *D* in con-

tact with the rear end of lever *C*. In this way, the point *E* constantly follows any irregularities in the work, and these are indicated on the dial *F*. On the exterior of sleeve *A* is a bushing *G*, which can be moved back and forth. The function of this bushing is to keep the axis of the gage, as nearly as possible, parallel with the center of the work, the sleeve being pushed back and forth, depending upon the distance from the face of the work that the measurement is taken.

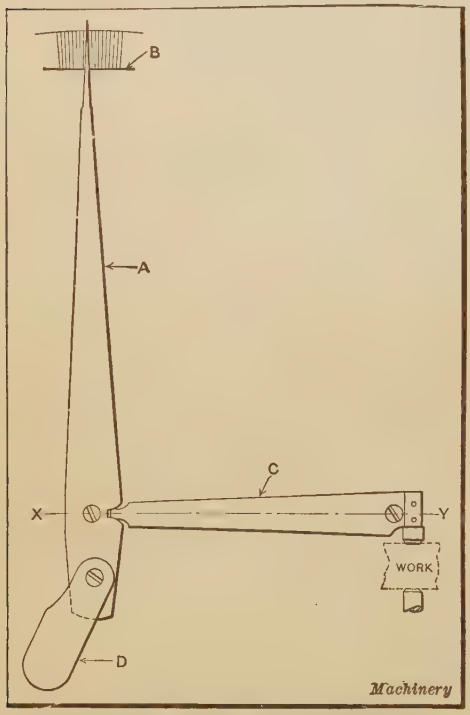


Fig. 6. Diagram illustrating Principle of Multiplying Lever Gage employing Two Arms connected by a Rack Tooth

There are several objections to this gage: One is the small multiplying movement which can be obtained; another is the unbalanced weight of the moving parts. In a gage built on the multiplying lever principle, the multiplication should not be less than 60 to 1, 100 to 1 being preferable. This provides for a movement of the indicating needle of a minimum of approximately $\frac{1}{16}$ inch for each 0.001 inch variation in the work. In the case of a multiplication of 100 to 1, the space between each graduation, representing variations in the work of 0.001 inch, would be 0.100 inch, which is still better.

Simple Type of Multiplying Lever Indicating Gage. — A multiplying lever indicating gage which can be used for accurate work is shown by the diagram, Fig. 6. This gage comprises two levers, which provide for a multiplying movement of 240

to 1; that is, variations in the work of 0.001 inch would cause a movement of 0.240 inch of the upper end of needle *A*. Segment *B* is, therefore, provided with graduations 0.024 inch apart, each space being equal to a variation of 0.0001 inch in the work. The connection between levers *A* and *C* is by means of a rack tooth, and lever *A* is counterweighted, as shown at *D*, making a spring unnecessary. One objectionable feature of this gage is the relation of the lower surface of the upper or movable anvil to the center line of lever *C*. For accurate readings, the measuring point should be in line with the axis *X Y*. As this gage, however, is only used for comparative measurements, and set by a master, this objection does not seriously affect its other advantages, which are simplicity of construction and great magnification.

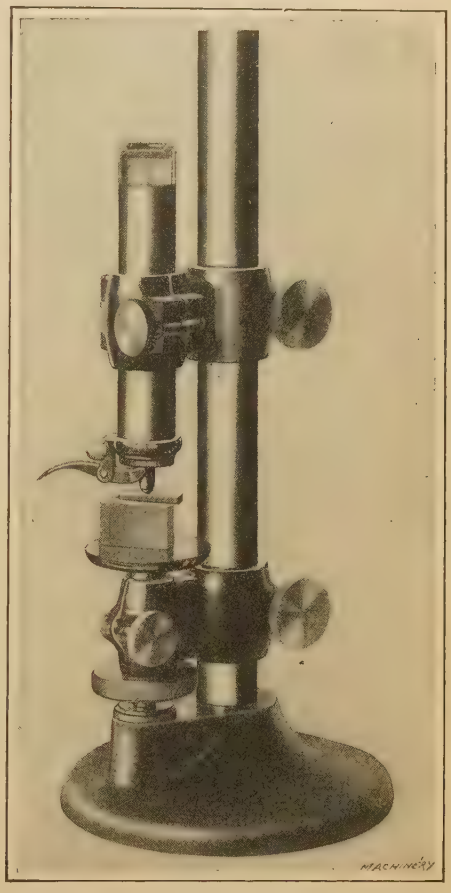


Fig. 7 Hirth Minimeter mounted in Stand Suitable for Average Run of Work

The Hirth Minimeter. — A multiplying lever indicating gage which comprises some very valuable features from the standpoint of both accuracy and construction is shown in Figs. 7 and 8. This gage, known as the Hirth minimeter, is used extensively by various concerns, and can be adapted to almost any class of work by simply arranging suitable stands for

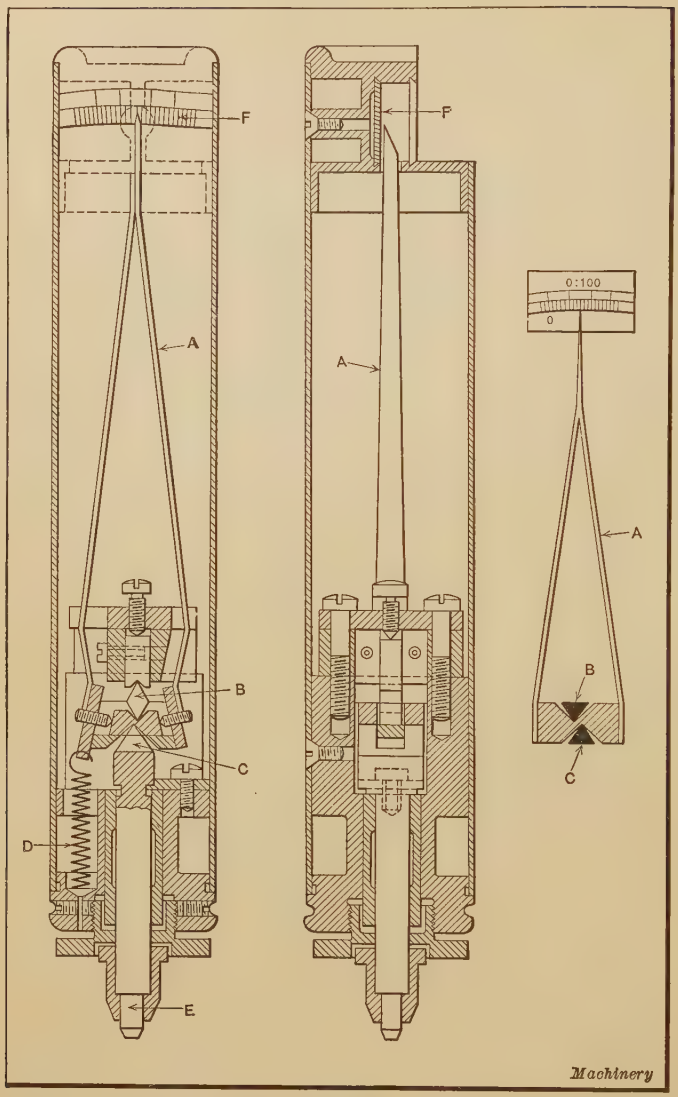


Fig. 8. Diagram illustrating Principle of Hirth Minimeter shown in Fig. 7

holding the measuring gage proper. Fig. 8 shows a sectional view through this gage, illustrating its working mechanism. The sensitive action of this gage depends upon the introduction

of a long lever arm A, which also serves as an indicating needle, and a short arm, the length of which is determined by the distance between the two knife-edges B and C. The bearing points of these knife-edges may be varied in order to provide adjustment for the apparatus. One of the advantages of this device is that it eliminates the necessity for lubrication and overcomes the disadvantage of play on dead centers. A light spring D holds the lever against the knife-edge and returns it to its normal position after measuring. A finger or pin E, bearing against the lower knife-edge, makes contact with the work to be measured. Movement of this pin causes the pointer A to swing over the scale F, due to the displacement of one knife-edge in relation to the other. The arc is graduated in different minimeters to give readings to 0.001 or 0.0001 inch. The entire mechanism is enclosed in a tube and the upper part is provided with an opening which permits the graduated scale to be seen and the indications of the pointer to be read off. The measuring instrument proper can be mounted in different holders.

Principles of Dial Indicating Gages. — The chief difference between a dial indicating gage and a multiplying lever indicating gage is the substitution of a graduated dial for a graduated segment, and the provision for making the needle travel one or more times around the dial, instead of just covering the segment of a circle. The dial is usually graduated so as to give readings to 0.001 or 0.0001 inch. In the dial indicating type of gage, some means must be provided for giving one or more rotations to the indicating needle, and for this purpose gears are generally employed. In the multiplying lever indicating type, no gears are necessary, as the pointer moves over an arc of a circle only and does not make a complete revolution. For the average run of work, especially in the inspection department, the multiplying lever indicating gage, when correctly designed, is superior to the dial type. For instance, the type shown in Figs. 7 and 8 has been found to be a most accurate indicating instrument for inspection use. In the following, a description will be given of some of

the principal gages made on the indicating needle and dial principle.

The Ames Dial Indicator. — In Fig. 9 is shown an Ames dial indicator attached to a simple holder and used for measuring the depth of the powder groove in a ring for a combination time and percussion fuse. The holder consists simply

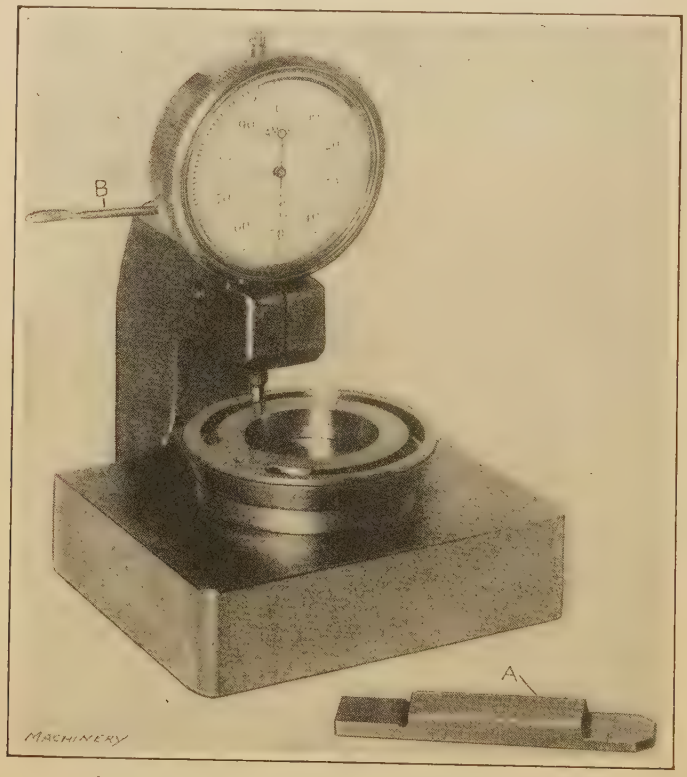


Fig. 9. Ames Dial Indicator used as Depth Gage

of a cast-iron block machined on the bottom and top surfaces and carrying a hardened and ground plug, which supports the fuse ring being measured. The bracket forming an integral part with this block is machined to receive the spindle of an Ames dial indicator. As has been previously mentioned, a dial indicator should not be depended upon when used on one

job for any length of time; it is always advisable to provide a setting block, as shown in the illustration at *A*, to check the instrument periodically. A spring keeps the measuring pointer in contact with the work; the pointer is lifted by means of lever *B*.

Dial Indicators employing a Train of Gears. — The internal mechanism of a dial indicator which is operated by a train of gears is illustrated in Fig. 10; it consists of a spindle *A* which works in hardened and lapped bushings inserted in the case

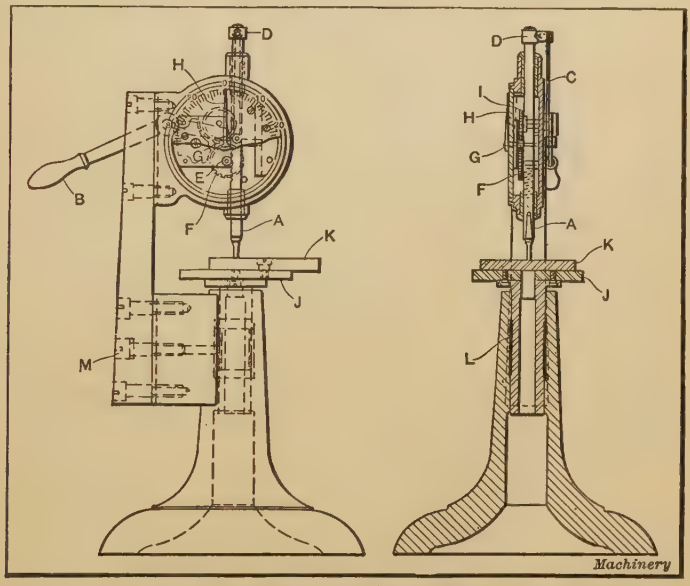


Fig. 10. Sectional View showing Construction of Dial Indicator operated by Gears

containing the measuring mechanism. The measuring spindle *A* is moved up and down by means of a handle *B*, to which it is connected by link *C* and collar *D*. When spindle *A* is raised the rack teeth cut in it mesh with a pinion *E*, which transmits motion to the gear *F*, pinion *G*, and needle *H*. Gear *I* is interposed to reduce the backlash. The dial is divided into one hundred equal spaces, and each graduation corresponds to a movement of the spindle of 0.001 inch. The table *J* is adjustable, and a plate *K* for holding the work to be measured is

attached to it by screws. The stud on which table J is held is screwed into a babbitt bushing L, the latter being clamped to the stud by the screw M, the babbitt being poured in after the stud is put in place.

Another type of dial indicator which has a greater multiplying movement than that shown in Fig. 10 is illustrated in Fig. 11. This gage is used for measuring such work as balance staffs, pinions, etc., for watches. It is provided with a dial having two hundred graduations laid off on its face. The

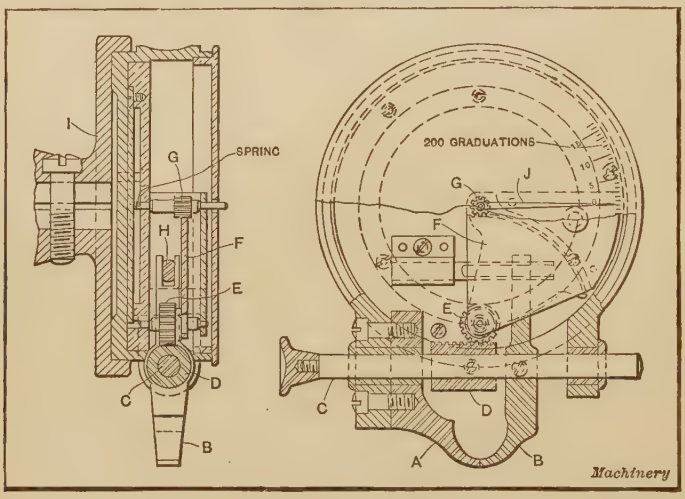


Fig. 11. Dial Gage of the Caliper Type

work to be measured is placed between the jaws A and B, which are separated by forcing in rod C to which jaw B is attached. Held on this rod by a screw is a rack D, which meshes with a pinion E having forty teeth. Pinion E is connected to segment gear F (the whole number of teeth in which should be 225), which meshes with pinion G attached to needle J. Jaw B, which is held by a screw to rod C, has a slot cut in its rear end which fits a flattened stud H, thus preventing the jaw from tilting. One complete revolution of needle J around the dial gives a corresponding movement between the jaws A and B of 0.080 inch, so that the space between each

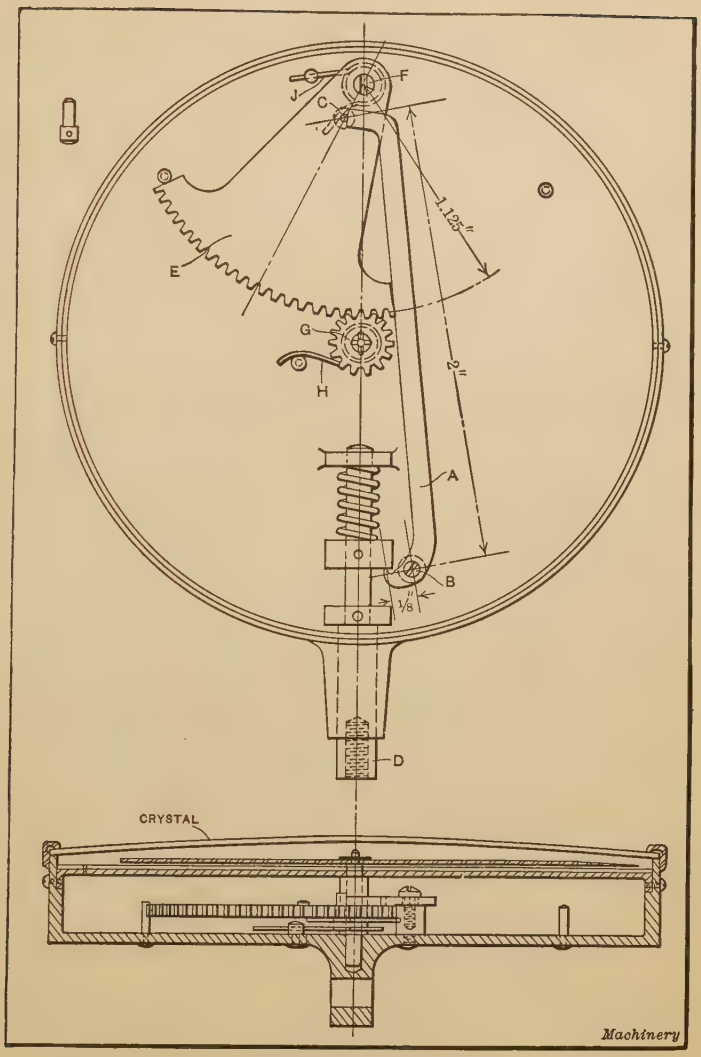


Fig. 12. Dial Test Indicator giving Readings to 0.0001 Inch

graduation of the dial represents a movement of the jaw of 0.0004 inch. The working mechanism of the gage is enclosed in a case and supported on a stand *I*, only partially shown.

A still more sensitive dial indicating gage or comparator is shown in Fig. 12. This gage also employs the pinion and gear

feature, and is so arranged that one revolution of the needle around the dial represents a movement of the anvil or measuring spindle of 0.010 inch; as the dial is divided into one hundred equal spaces, this means that the space between each graduation is equal, theoretically, to a 0.0001-inch movement of the anvil. In a commercial gage, however, the movement of the needle varies somewhat over different parts of the dial. The working parts consist of a lever *A*, fulcrum screw *B*,

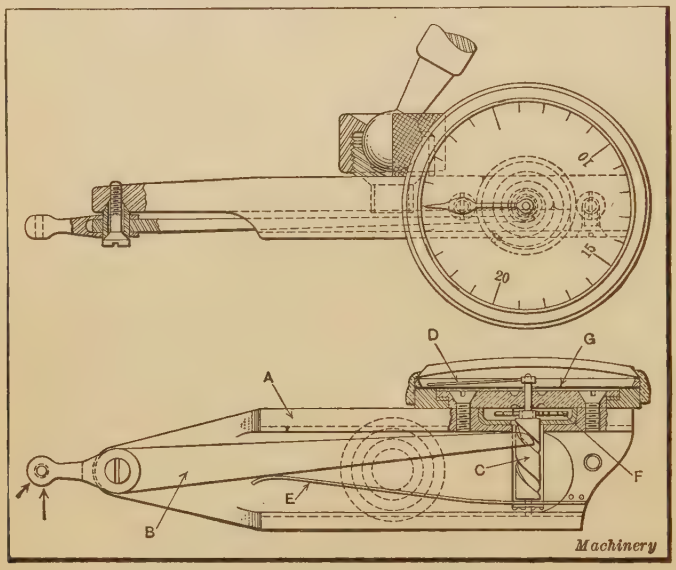


Fig. 13. Lowe Dial Test Indicator

plunger *D*, fan gear *E*, and pinion *G*. The gage operates as follows: When brought in contact with the work, plunger *D* is moved and the flange on this plunger moves the short end of lever *A* with which it is kept in contact by the action of spring *J* on the segment gear and the spiral spring on the plunger. In this way, a uniform contact is maintained between the long end of lever *A* and the pin *C*, and also between the flange of the plunger and the short end of lever *A*. The movement of lever *A* causes the required movement of the segment gear, which turns the pinion and the pointer.

Dial Indicator with Worm for Rotating Needle. — An indicating gage of the dial type in which a train of gears is dispensed with is shown in Fig. 13. This indicator employs a worm in place of a train of gears for conveying the rotary movement to the indicating needle. As shown in the illustration, this gage consists principally of a body *A* milled out on one side to receive the indicating lever *B*, which is attached, as shown in the sectional view, to the forward end of body *A*. The forward end of this lever is provided with a friction joint, which allows the contact point to be moved around through

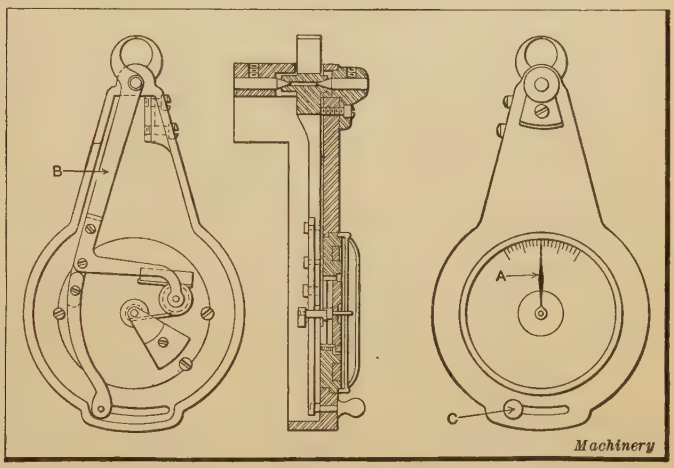


Fig. 14. Dial Indicator of Caliper Type

180 degrees to any required position, thus greatly increasing the usefulness of the instrument. The rear end of lever *B* is provided with a projection fitting in the groove in worm *C*. This worm is held in somewhat the same way as a staff in a watch, and on its extreme upper end it carries an indicating needle *D*. The needle is retained at zero by means of the flat spring *E* and a hairspring *F*. The dial *G* is divided into twenty-five equal parts, the distance between each graduation representing a movement of the lever *B* of 0.001 inch. The dial is so arranged that it can be turned around to bring the zero point in line with the needle when the latter is at rest.

In this instrument the objectionable feature of backlash is avoided, and it has been found both reliable and sensitive. A plate, not shown, covers the internal mechanism by fitting in a dovetail groove in the side of the body and is held in place by a screw. By the addition of several arms, etc., this device can be used for various purposes.

Dial Indicator of the Caliper Type. — Another dial indicating gage which does not depend for its magnifying movement upon a train of gears is shown in Fig. 14. In this gage, the hand *A*, which travels around the dial, is operated by means of a fusee chain that is wound around the spindle to which the hand is

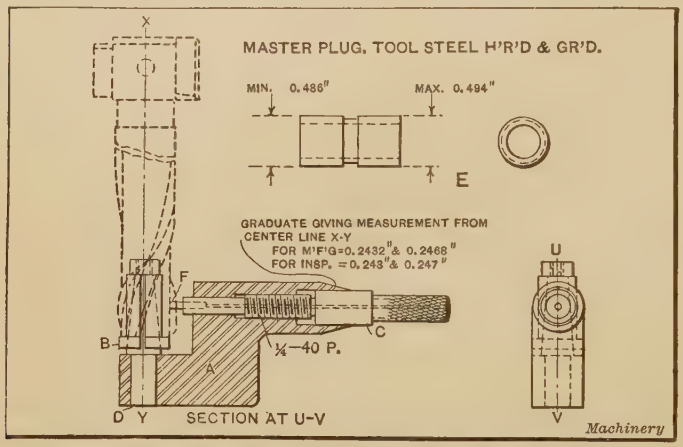


Fig. 15. Micrometer Type of Indicating Gage used for Testing Rifle Part

fastened; the chain is connected to the movable jaw lever *B*. A hairspring, not shown, surrounds the lower end of the spindle to which the hand is attached in such a way as to pull the indicator hand toward zero and keep the chain wound up as far as the caliper jaw will permit. The jaws are separated by pushing the button *C* to the right, which operates the long lever *B* attached to the movable jaw.

Micrometer Indicating Gages. — An indicating gage which is capable of wide application is the micrometer type of gage. This generally consists of a micrometer spindle held in a suitable frame, which latter, as a rule, also supports the work and enables

measurements to be taken at several points when desired. A simple application of the micrometer type of gage is shown in Fig. 15; this is used for measuring the diameter of a military rifle bolt at the root of the spiral ribs. It consists principally of a frame *A* holding a split sleeve *B* and a micrometer spindle *C*. The sleeve *B* is held on a conical plug *D* by a nut and is split so that it can be made to fit snugly in the hole in the bolt. To lay off the manufacturing limits on the gage, the master plug *E* is placed on sleeve *B*, and the measuring point *F* is brought

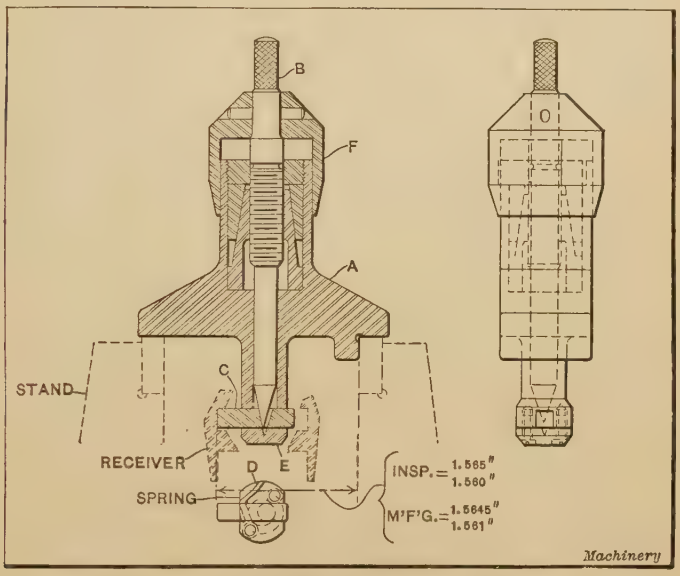


Fig. 16. Micrometer Gage for Testing Location of Bolt Guide Groove in Military Rifle Receiver

in contact with it. This master plug *E* is also used for checking the gage at frequent intervals.

Another interesting type of micrometer indicating gage is shown in Fig. 16. This is used for testing the location of the guide in a receiver for a military rifle. The receiver is held in a gaging fixture, being located by plugs fitting in both ends. The upper surface of the fixture is provided with hardened and ground parallel strips, on which the micrometer gage is located, as shown. The gage consists of a base *A* provided with a lug

which fits against the hardened and ground measuring blocks on the stand. A cone-pointed and threaded spindle *B* extends downward through the center of the body of the gage and actuates a measuring finger *C*. This finger is held by means of a flat spring *D*, shown in the lower view, which fits in the slot in the finger and also in the base of the gage. A cap *E* is fastened to the stem of the gage by two screws, as shown, to prevent the finger *C* from dropping out. The spindle *B* is provided with forty threads per inch and is pinned to a thimble *F*. The gradu-

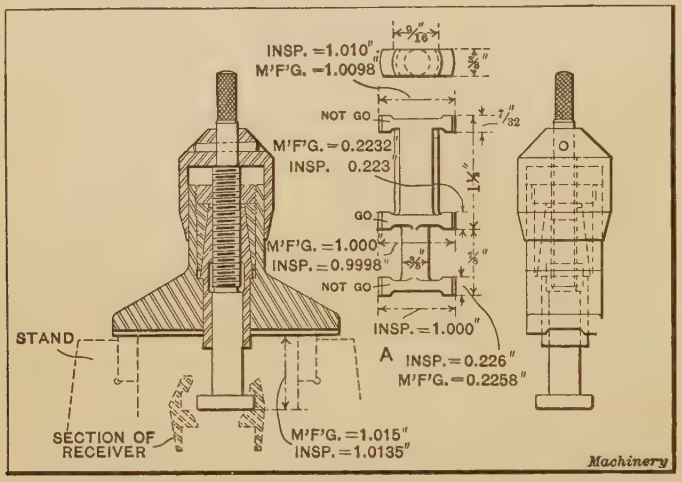


Fig. 17. Another Micrometer Gage for Testing Bolt Guide in Military Rifle Receiver

ations on this thimble are laid out after the gage has been assembled and set by means of a master.

A somewhat similar micrometer gage is shown in Fig. 17. This gage is used for testing the distance from the center of the receiver to the bottom of the bolt sleeve guide slots on a military rifle. A stand similar to that used with the gage shown in Fig. 16 is used with this gage for holding the work; this gage is of practically the same construction as that shown in Fig. 16, except that the spindle is provided with a head which acts as a measuring point. A standard reference block is provided for use in setting the spindle when it becomes worn or inaccurate.

There are, of course, many other applications of the micrometer spindle to accurate gaging, but the examples given here show the principles involved, which are subject to considerable modification for different uses.

Three-point Indicating Gages. — In machining work which is eccentric or unbalanced, considerable difficulty is sometimes experienced in producing a truly cylindrical hole or bearing, due to play in the machine bearings or other causes. When the

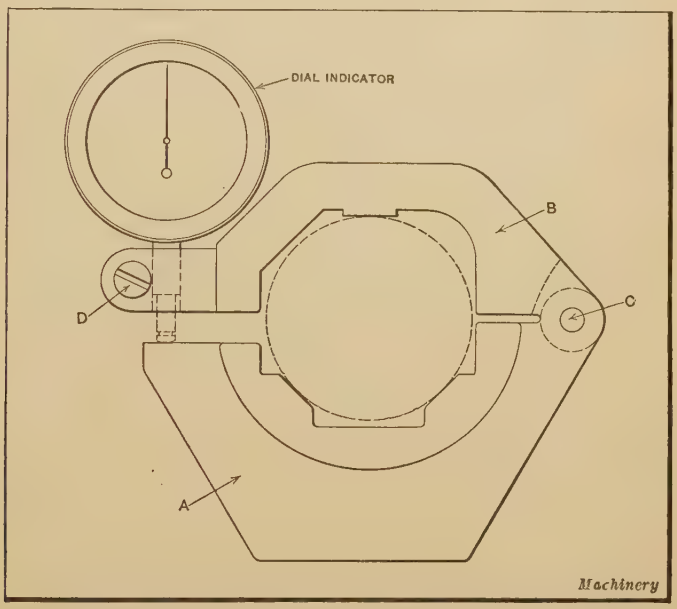


Fig. 18. Three-point Dial Indicating Device for Testing Crankshaft Bearings

forces opposed to each other are so unbalanced that a three-cornered effect is produced, the ordinary two-point measuring instrument will not detect the error that exists. The only way of successfully measuring the work to find whether it is truly cylindrical or not is to employ a three-point measuring instrument. Several devices have been made for this purpose, one of which is the ordinary micrometer provided with a special two-point anvil, the third point being formed by the spindle of the micrometer.

Another device, which employs a dial indicator, is shown in Fig. 18. This is used for measuring the crankpins of automobile crankshafts and, as shown in the illustration, consists principally of two blocks *A* and *B*, hinged at the point *C*. The upper block *B* is machined on one end to receive the spindle of the dial indicator, which is held in place by means of the screw *D*. When used, the indicator is swung open, slipped over the work and then brought down in contact with it, so that the spindle rests on the upper surface of block *A*. It is then possible to tell whether the bearing is out of round or of the correct diameter. The gage is set to the zero point by means of a master plug made to the same diameter as the crankpin.

The three-point indicator illustrated in Fig. 18 has one disadvantage in that it is comparatively slow to operate and is rather

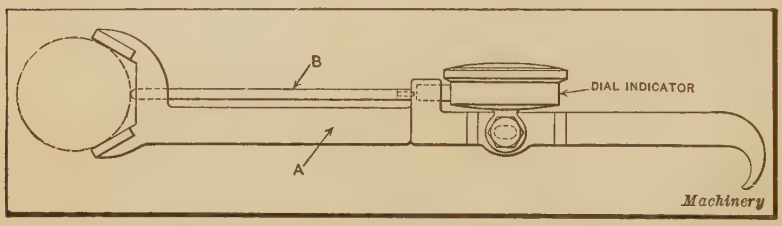


Fig. 19. Three-point Dial Indicator for Testing Crankpin Bearings, which can be applied while Work is in Motion

bulky to handle. An improvement over this device, which has three points located 30 degrees apart, is shown in Fig. 19. This device is also used for testing the crankpin bearings of a crankshaft and is so constructed that it can be used very rapidly. In fact, it can be applied to the work while the latter is in motion. It comprises a main holder *A* formed at the forward end to the shape shown, and carrying two hardened, ground and lapped blocks. The rear end of the holder is provided with a hook to facilitate gripping in the hand. The dial indicator, as illustrated, is fastened to this holder. A spindle *B* passing through two bearing supports in the holder proper comes in contact with the spindle of the indicator. When in use, this instrument is set to the desired diameter by means of a master, and can then be applied directly to the work while the latter is in motion and the

reading taken off on the dial indicator. For many classes of work, this type of instrument will be found to be much superior to the micrometer caliper, in that it is quicker to operate and can be used in connection with the limit system of manufacture.

Three-point Indicators for Internal Work. — The indicating devices shown in Figs. 18 and 19 are used for external measure-

Fig. 20. Hirth Minimeter fitted up for Use as an Internal Gage

ments. Fig. 20 shows a device which can be used for internal work. By the addition of a simple attachment, the Hirth minimeter, which has previously been described, is here used for internal gaging. The special holder is fitted around the body of the lower portion of the indicator, and carries one adjustable and two rigid points, the former being connected by means of a lever to the spindle of the indicating lever. Fastened to the bracket of this attachment are three rollers against which the

work is pressed, and which keep it straight while it is being tested. The two rigid points are adjustable for wear, and all three points are provided with ball points. With this device it is possible to tell if the hole is of the correct size, or if it is out of round, tapered, etc.

Gas Engine Cylinder Gage. — A three-point dial indicating gage designed particularly for testing the bore of automobile

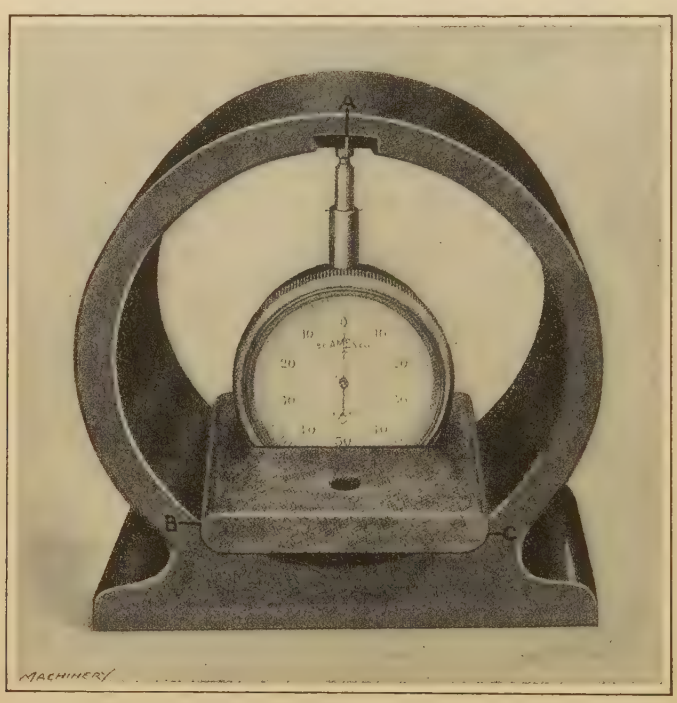


Fig. 21. Ames Gas Engine Cylinder Gage

cylinders is shown in Fig. 21. The illustration shows the gage inserted in the standard ring which is used for setting the needle at zero. This ring has a diameter equal to that of the cylinder it is desired to test. The base, holding an Ames dial indicator, forms two points, *B* and *C*, and the plunger of the indicator forms the third point *A*. With this device, it is possible to tell whether the cylinder is large or small, out of round, or tapered.

Another three-point gas engine cylinder gage of simple construction is shown in Fig. 22. This gage comprises a standard dial test indicator, which is attached to a frame by a thumb-nut, as shown. In this frame, which is made of cast iron, are set three buttons A, two on one side and one on the other, giving a three-point bearing. The bearing points are set 120 degrees apart, and two of the opposite points and the plunger of the dial gage are set in the same plane, the third being set lower a distance equal to about one-third of the cylinder diameter. The dial gage is provided with a slip ring, so that the pointer may be set to zero no matter what its position may be. In using this instrument, it is pushed into the cylinder, dial first, from the head or compression end, assuming that the cylinder head is detachable. Then, with the aid of an electric flash light, the operator or inspector may easily watch the variations in the cylinder diameter. The instrument should be pushed through the cylinder slowly, care being taken to have all three corners bearing on the cylinder bore. If it is desired to use this instrument as a micrometer, it can be set by a standard ring.

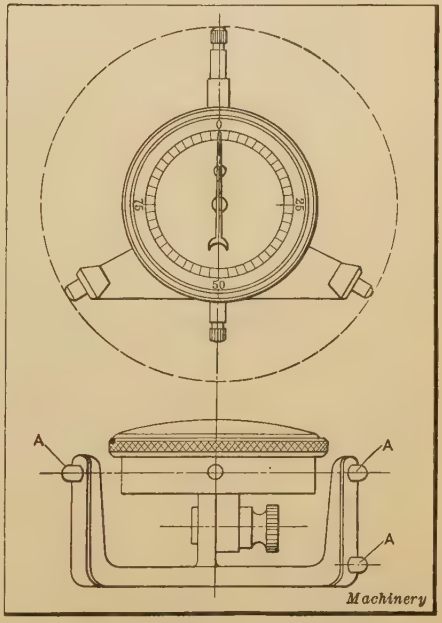


Fig. 22. Gas Engine Cylinder Gage having a Three-point Bearing on Its Base

Star Gages. — A type of gage which was developed especially to meet the demand for a convenient and accurate instrument for gaging the bores and jackets of guns of all sizes, from the one-pounder rapid-fire gun up to the largest caliber, is shown in Fig. 23. This gage consists principally of a body A, in which three

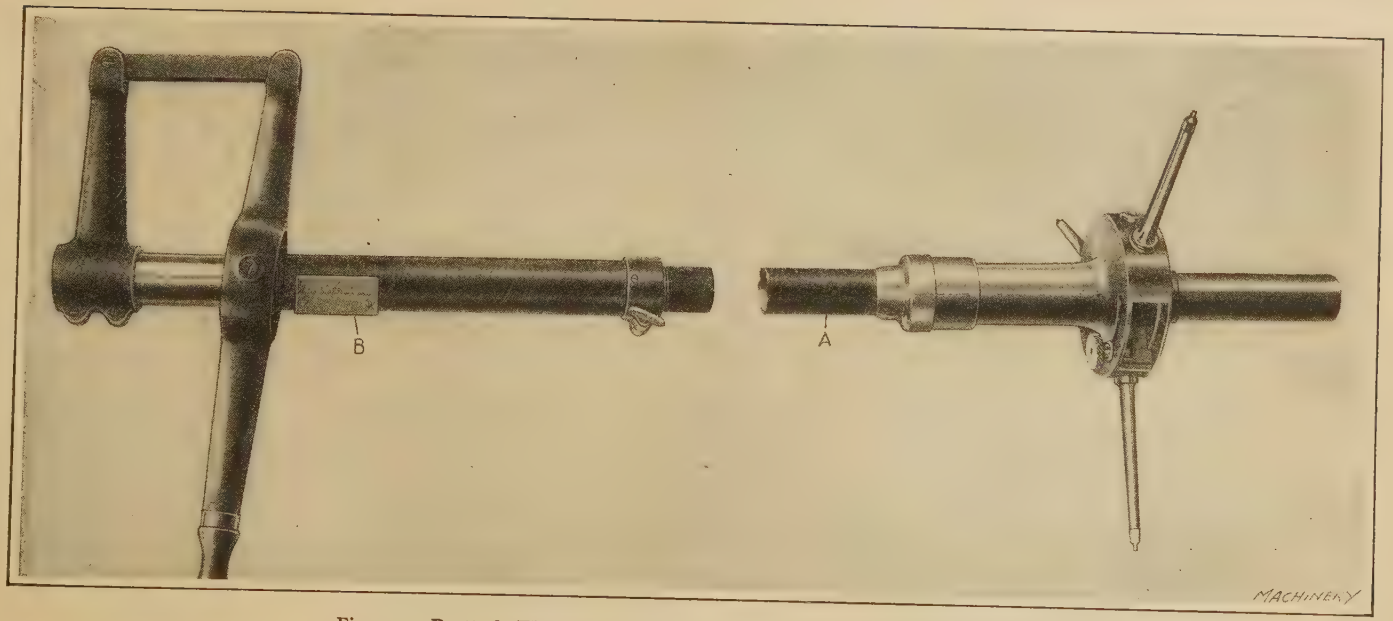


Fig. 23. Pratt & Whitney Star Gage with Three-point Measuring Head

measuring heads are held (four can be used if desired); these heads are radially adjustable, having tapped holes in the outer end to which various measuring points of any suitable length can be attached. The radial adjustment of the points is controlled by a central wedge or cone, which may be moved longitudinally, and the heads are fitted so that they may rotate freely when gaging the rifling of a gun, or may be locked for regular work. The body of the gage is made of seamless drawn steel tubing, provided with means for readily coupling and uncoupling to produce any desired length. The tubular body *A* is graduated throughout its entire length in quarter inches. This is essential when it is desired to make a record of the condition of the bore by taking measurements at regular intervals.

The operating head shown to the left is made with a sliding member connected to the jointed rod by which the wedge in the measuring head is given its longitudinal movement. The operating lever shown is provided to give the necessary delicacy of movement, and also facilitates the operation of the gage. The scale and vernier shown at *B* enables the variations from the required diameter of bore to be read at a glance. For each diameter of bore to be gaged, a standard ring is usually furnished for setting the gage. Suitable supports hold the standard ring concentric with the measuring head when the points are brought in contact with it, and then the vernier is adjusted so that the zero lines coincide. For the smaller gages, the vernier gives readings to 0.0005 inch, and to 0.001 inch on the larger sizes.

When gaging bores of considerable length, it is necessary to support the gage and to keep it from sagging, which would introduce a small error in measurement. Therefore, supports such as shown in Fig. 24 are used. These are set in the bore of the gun being measured and the gage is slipped through the hole *A*. The legs of the supports are then adjusted so that the gage is held central with the bore of the gun. A centering device, as shown in Fig. 25, is also provided when desired. This consists of a central hub with three graduated radial arms, upon which are mounted sliding jaws that project into the bore; one of the jaws is provided with a screw adjustment for binding

the device in the bore. The central hub has a slot at the top to receive the gage tube which rests on two rollers, permitting the gage to move freely without danger of marring the surface of the tube.

Application of Indicating Gages. — Gages of the indicating type are gradually superseding solid gages on many classes of work, because of their greater sensitiveness. For instance, they are used for testing external and internal cylindrical work, parallelism of shafts, relation of angular surfaces, height and

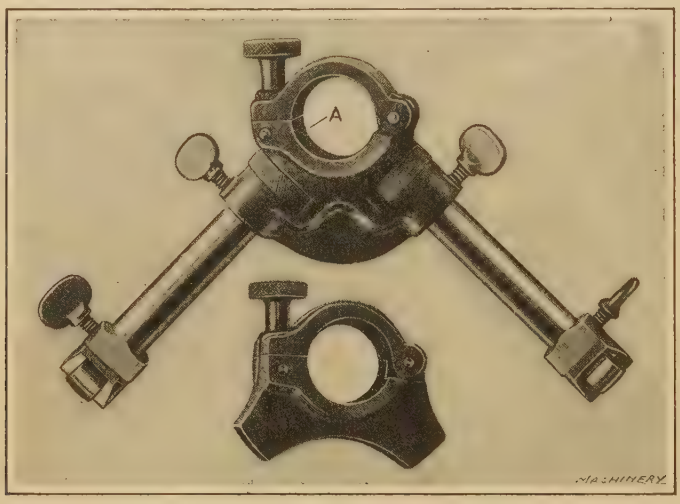


Fig. 24. Supports used for Steadying Pratt & Whitney Star Gage when used in Long Lengths

depth of shoulders and holes, concentricity of parts, cam shapes, strength of springs, etc. In the preceding pages, examples have been shown of the types of indicating gages used for cylindrical external and internal work; in the following, attention will be given to other applications, including gages used for testing balls and ball bearings, and the use of box-type inspection fixtures for work having a number of holes that must bear a certain relation to each other.

Testing Parallelism of Shafts. — For testing the parallelism of shafts, the indicating gage is very satisfactory. One means of

determining if a shaft lies in a plane parallel with the base of a machine is illustrated in Fig. 26. In this case it is desired to determine whether or not the needle bar lies in a plane parallel with the base of a sewing machine. The gage consists of a steel base *A* resting on four feet *C*, which, as shown, come in contact with the top surface of the table. These feet are hardened, ground and lapped in the same plane. The hardened tool steel plungers *B* which come in contact with the needle bar are flat

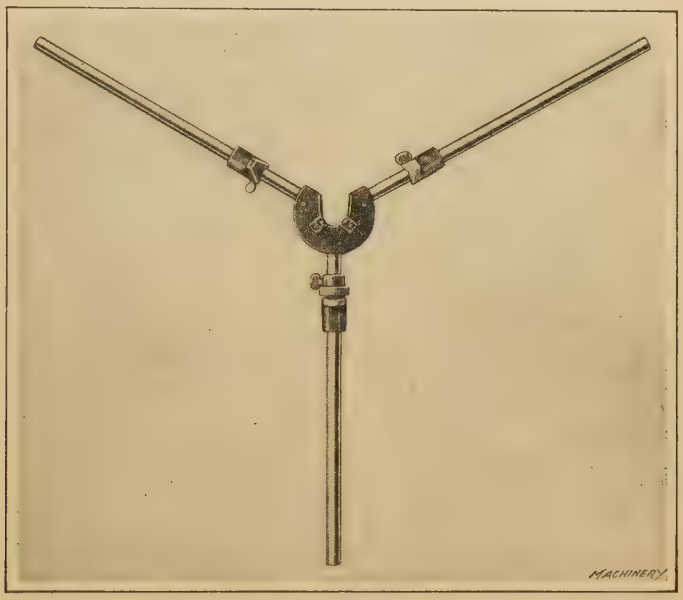


Fig. 25. Centering Device used with Pratt & Whitney Star Gages

on one end and spherical on the other. These plungers fit loosely in the bearings *E* and are held from dropping out by adjusting nuts *F*. Fulcrumed on studs *G* are the pointers *D*, which have hardened projecting arms that are in contact with the upper end of plungers *B*. The sheet steel frame *H* is bent at right angles along the bottom and screwed to the base. Right- and left-hand coil springs *L* act in opposition to the plungers so that they turn the pointers to the extreme outer position, when the gage is not in use. When the pointers are to be adjusted, the instrument

is set on parallels, and a height gage inserted under each plunger successively, the plungers *B* being adjusted so as to bring the pointers to zero. On this particular gage a limit of ±0.005 inch is provided.

Testing Relation of Surfaces at Right Angles. — Many different indicating devices have been constructed for testing the

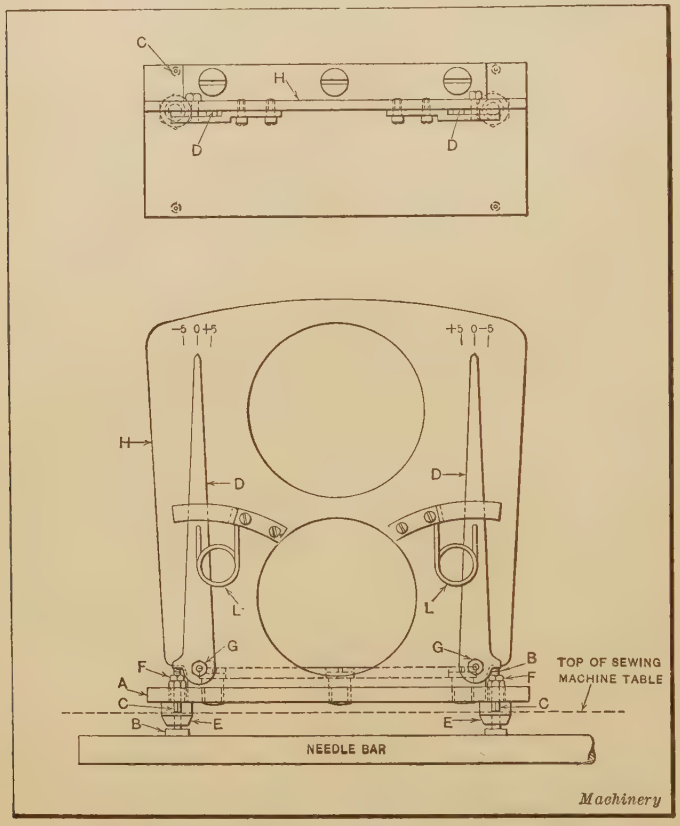


Fig. 26. Indicating Gage for Testing Parallelism of Shaft

relative positions of angular surfaces, and in Fig. 27 is shown a simple gage for determining if the base of a gas engine cylinder casting is square or at right angles with the bore. This gage consists of a base *A*, frame *B*, pivot *C*, and indicating lever *D*. The body of the gage is made in two parts to facilitate machining.

The indicating lever support is fastened to the body with screws and dowel-pins, and extends into the cylinder so that the center of the lever pivot is somewhat below the face of the flange of the casting. By placing the gage on the cylinder flange and bringing the knife-edges *a* and *b* on the lever into contact with the cylinder wall, any variation is shown by the mark at the upper end of the gage. This can be so laid out that plus or minus

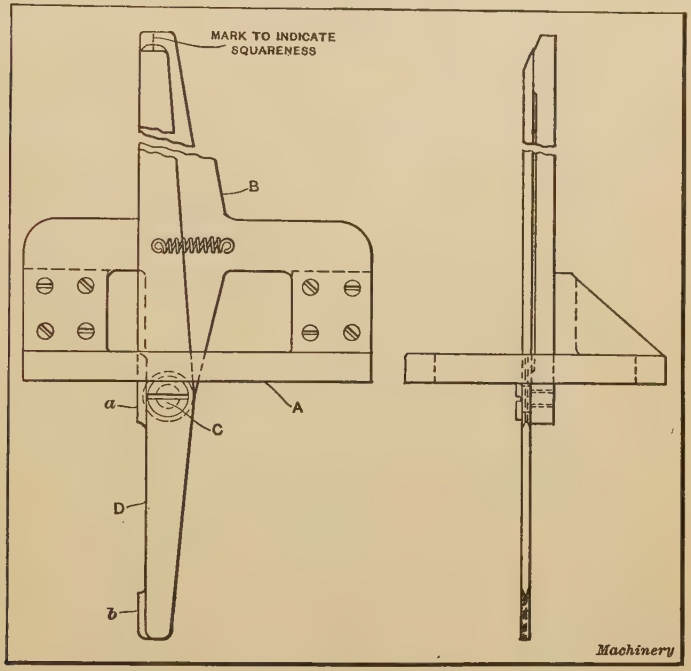


Fig. 27. Indicating Gage for Testing Squareness of Base of Cylinder Casting with Bore of Cylinder

limits can be provided. The reason for placing the pivot below the cylinder flange is to have it take the thrust when the indicator is moved against the side of the cylinder bore. A spring above the pivot holds knife-edges *a* and *b* in contact with the cylinder wall. The gage is simple in construction and operation.

Indicating Height and Depth Gages. — For determining the relative heights of two shoulders, a height or depth gage is necessary. Gages of the multiplying lever or dial indicating

type are best adapted for this purpose. Fig. 28 shows a height gage constructed on the multiplying lever principle. It consists of a base *D* having two shafts *E* fastened to it, connected at the top by a link. On these shafts is a sliding member *G*, which can be locked securely in any position by screw *H*, acting upon two clamping bolts, thus obviating springing of the gage when in use. The adjusting nut *C* operates part *I*, which is carefully fitted in the slot. On the same part is a shoulder *J* to which the

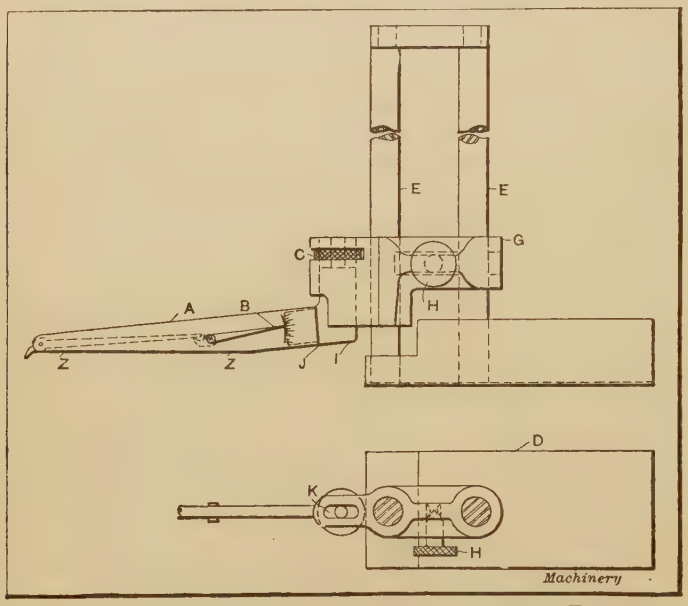


Fig. 28. Indicating Height Gage for Tool-room Use

arm *A* is fastened. This arm is made from tubing and is similar in shape to opening *K*. It is made a tight fit on the holder at *J*, and a pin put through to fasten it securely. The oblong tube *A* is now cut along the line *ZZ*, and inside of it are placed the levers which are arranged to give readings to one-half thousandth inch. While this gage has many admirable features from the point of view of accuracy, it is only suitable for tool-room use, and not for manufacturing or inspection purposes. It is evident that a gage designed for inspecting any particular piece should be so made that universal adjustment is not possible. In other

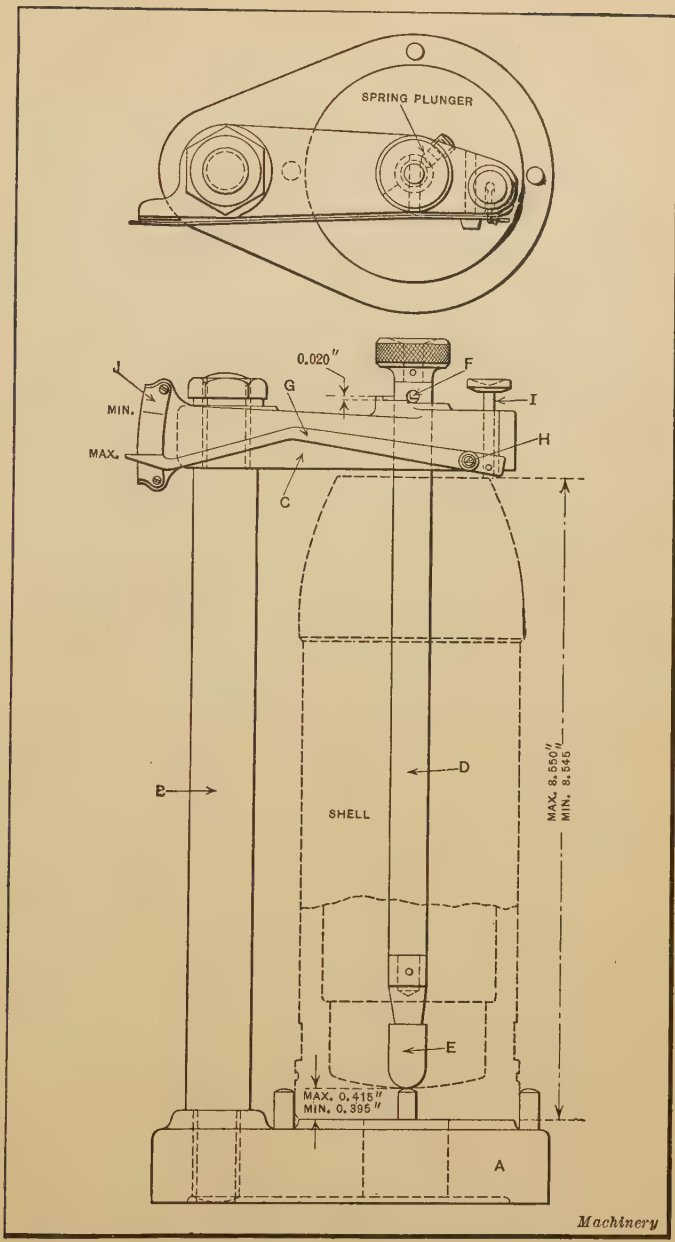


Fig. 29. Indicating Height Gage used for Inspecting Thickness of Base and Over-all Length of Shrapnel Shell

words, its range should be limited to the particular work for which it is designed.

Indicating Gage for Testing Shrapnel Shells. — An indicating gage which fulfills two functions — gaging the over-all length as well as the thickness of the base of shrapnel shells — is shown in Fig. 29. This gage comprises a base *A* in which three pins are driven to center the shell; an upright *B* for supporting the indicating mechanism; and attached to the top of upright *B*, an indicating lever support *C*, which is so mounted that it is free to swing in an arc. The device for indicating the thickness of the base of the shell consists of a rod *D* that has a hardened and

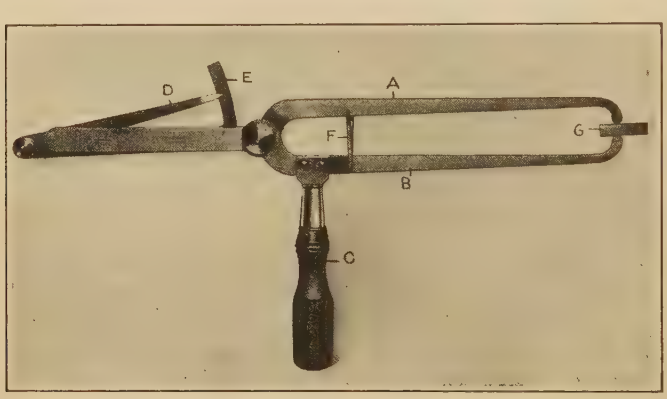


Fig. 30. Caliper Type of Thickness Gage for Testing Thickness of Walls of Cartridge Cases

ground tool steel point *E* and a limit pin *F*. A boss formed on bracket *C* is provided with a step, the height of which is 0.020 inch, or the manufacturing limit allowed on the thickness of the base. The limit pin *F*, when brought around, must come with its indicating surface between the top and bottom of this step. The desired thickness is indicated when the lowest surface of limit pin *F* is located equidistantly between the high and low points on the limit step. To insert the shell in the gage, it is necessary that rod *D* be removed from bracket *C*.

The indicating device for the over-all length consists of a multiplying lever *G*, pivoted to bracket *C* at the point *H*, and

attached by a pin to plunger *I*. Plunger *I* is hardened and ground on its lower surface and makes contact with the end of the shell. The reading is obtained from the segment *J*, which indicates the limits on the work. This fixture is free from springs and is of simple construction.

Indicating Thickness Gages. — The simplest form of indicating thickness gage is the micrometer caliper, but as this type of gage is well known, it will not be described here. Another simple form of indicating thickness gage is shown in Fig. 30. This is designed especially for gaging the thickness of the wall of cartridge cases near the head end. It consists principally of two caliper jaws *A* and *B*, which are made long enough to reach down into the case, a handle *C* for holding the gage, indicating pointer *D*, and graduated arc *E*. A combination locating stop and support *F* is also provided to keep the jaws in alignment with each other, and locate their measuring points at the desired distance from the open end of the case. When in use, the jaws of this gage are slipped over the walls of the case, and readings taken at various points around the circumference. It is tested from time to time by the setting block *G*.

Another indicating thickness gage which is used for the same purpose as that illustrated in Fig. 30 is shown in Fig. 31. As this illustration shows, this gage is of the stand type, and supports the cartridge case being inspected by means of a horseshoe support *A* held on upright *B*. Two other posts *C* and *D* carry the gaging points, one of which, *E*, is held rigidly in post *C*, while point *F* is free to slide and is kept out by means of spring *G*. The upper end of post *D* is notched to form a limit step, and plunger *F* is provided with a line which must come between the two steps when the wall is of the correct thickness. A height gage *H* is also provided which enables the thickness of the head to be checked at the same time that the wall is inspected.

An indicating gage for testing the thickness of the walls of shrapnel shells at a point slightly above the powder pocket where the inner wall is straight, is shown in Fig. 32. This consists of a sheet-steel frame *A* carrying a bushing *B* which fits in the nose of the shell, a roller support *C* for keeping the gage

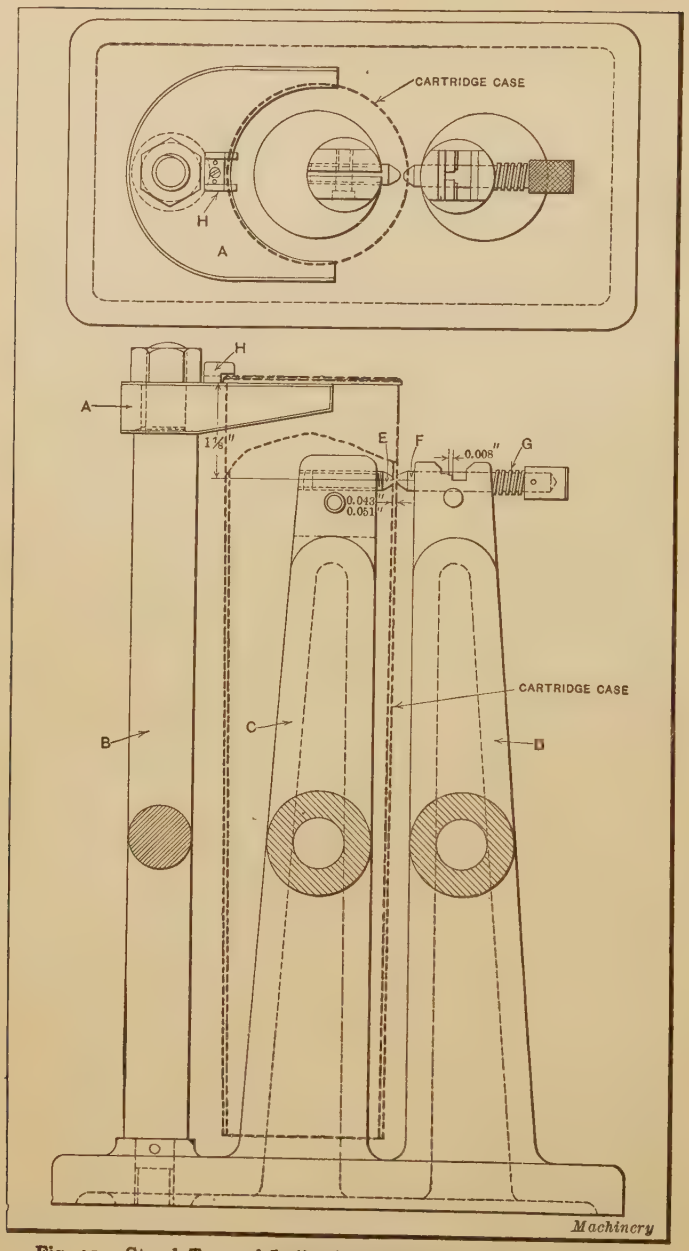


Fig. 31. Stand Type of Indicating Thickness Gage for Testing Walls of Cartridge Cases

in line with the axis of the shell, and two measuring points *D* and *E*. Measuring point *D* consists of a hardened, ground and lapped block, which is riveted to the frame *A*; point *E* is a roller attached to a multiplying lever *F*. Lever *F* swings over a marked segment *G* which indicates the limits on the work, and a flat spring *H* keeps roller *E* in contact with the work. In using this gage, the member *I* is inserted in the shell and located by bushing *B*. The gage is gripped by the handle and moved around the circumference of the shell to test its thickness at various points. Block *J* is used to test the gage for wear.

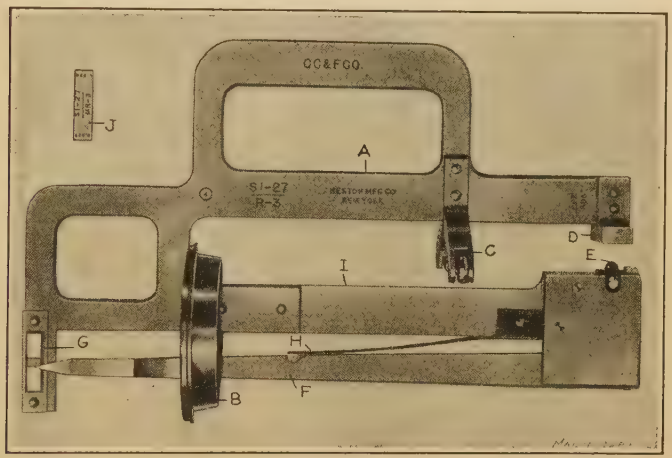


Fig. 32. Indicating Thickness Gage for Testing Thickness of Walls of Shrapnel Shells.

Concentricity Gages. — There are several methods of determining whether or not a hole and an exterior surface are concentric with each other. The simplest way is to use a gage of the type shown in Fig. 33. This is not an indicating gage, but is shown here simply to illustrate the least expensive type of gage for concentricity gaging. It is built along the lines of the standard plug gage, with the exception that it is provided with a limit bar which controls the amount of eccentricity of the hole and the exterior surface. Bar *A* is provided with a step giving the "go" and "not go" limits. It is also formed to a knife-

edge to reduce the amount of bearing surface to a minimum. The plug *B* fits into the hole in the work and the knife-edge on bar *A* is located at a distance from the axis of the plug equal to the radius on the work.

Another simple gage that is used to test the relation of one hole to another, the two holes being eccentric to each other, is

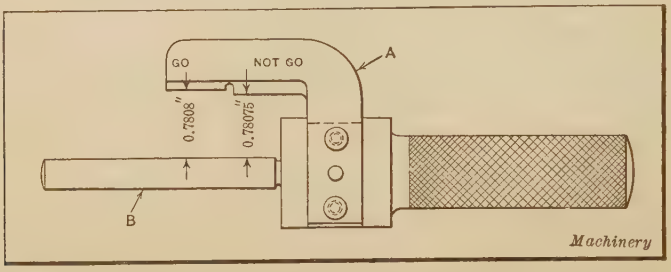


Fig. 33. Simple Type of Concentricity Gage based on Limit Principle

shown in Fig. 34. This gage is of simple construction and is also built along the lines of the plug gage, having two ends, one giving the "go" and the other the "not go" size. The gage consists of a body *A* in which two plugs *B* and *C* are fastened

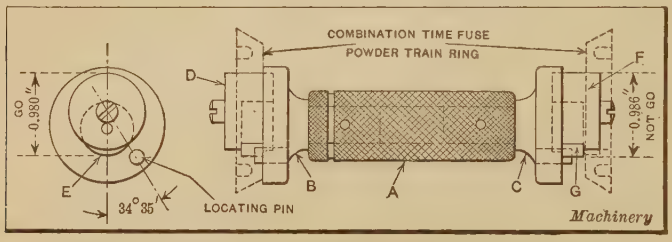


Fig. 34. Another Concentricity Gage of the Plug Type

by pins, as shown. Two disks are also fastened to the faces of plugs *B* and *C*, one disk *D* being made so that it enters one of the holes in the work, which is a combination time-fuse powder train ring. The other disk *E* is made to fit in the hole which is eccentric to the one in which plug *D* fits. Plugs *D* and *F* are of the same size, whereas plugs *E* and *G* are of different sizes, the difference in diameter being such as to control the manufacturing limits on the work. The center location of the two disks in

relation to each other is the same on both ends of the gage, the difference in diameter being the factor that controls the limit on the work. In using this gage, the work is tried first on the "go" and then on the "not go" end. If plug *E* goes in and plug *G* does not, the work is satisfactory.

Testing Piston-pin Holes with Relation to Body of Piston. — Two interesting gages, one for testing the squareness of the piston-pin hole with relation to the exterior surface of the piston, and the other for testing the concentricity of the piston-pin hole with relation to the exterior surface of the piston, are shown in Fig. 35. The gage shown at *A* is for testing the square-

Fig. 35. Indicating Gages for Testing Squareness and Concentricity of Piston-pin Hole in Relation to External Diameter of Piston

ness of the piston-pin hole with relation to the body of the piston, and consists of a plug *a*, which is made a good fit in the piston-pin hole, and a bracket *b*, held in plug *a* by a screw *c*. Bracket *b* carries a micrometer spindle *d* which is used for testing the squareness of the hole.

In applying this gage, the plug is pushed into the piston-pin hole until the shoulder *e* is in contact with the surface of the piston. The micrometer spindle is then brought to bear first at one end — near the head — and then near the base of the piston, and the amount of variation between the two points is read off on the thimble of the micrometer. The plug is made

to enter freely enough into the piston-pin hole, so that the gage can be turned around to bring the micrometer spindle into the desired position.

The gage shown at *B* is of somewhat similar construction, except that a dial indicator is used in place of the micrometer screw. The dial indicator *f* is held in a bracket *g*, as illustrated, and is adjusted in this bracket so that its indicating point or plunger comes directly in line with the vertical axis of the piston when shoulder *h* of the plug is in contact with the surface

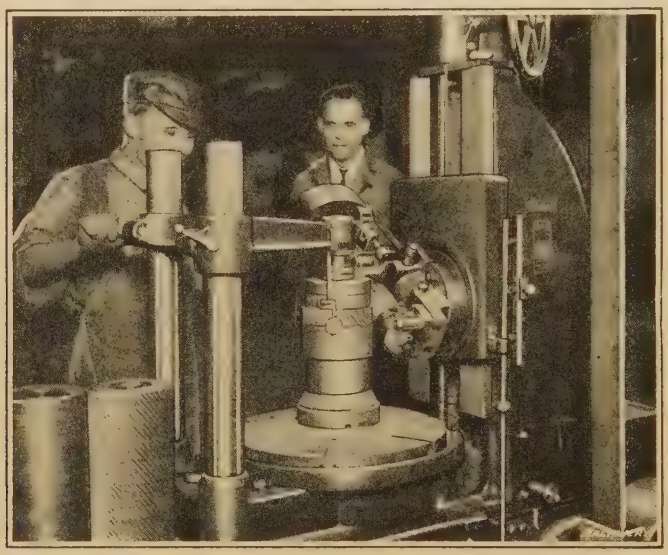


Fig. 36. Testing Concentricity of Gears on Gear-hobbing Machine

of the piston. After one side of the piston has been tested, the gage is removed, the work turned around, and the other side tested to see if the piston-pin hole is exactly central with the exterior surface of the piston. The gage is provided with two feet, as shown, for supporting it.

Testing Concentricity of Gear Blanks. — One method of testing work to see whether it is concentric or not before machining is shown in Fig. 36. This illustration shows a dial indicator testing gear blanks which are to be cut on a gear-hobbing machine.

After a series of blanks is fastened on the work-holder and the work-holder supports are put in place, the dial indicator is brought in contact with the work and held by clamps as shown. The work-spindle is then rotated, and the movement of the dial indicator shows whether or not the exterior surface runs true; if not, it is an indication that the work has not been accurately machined or that the work-arbor has been thrown out of correct alignment.

Testing Concentricity and Radial Position of Cutter Teeth. — A testing device used by the Union Twist Drill Co. for determining whether or not the teeth of milling cutters are equidistant from the center, so that they will do their correct share

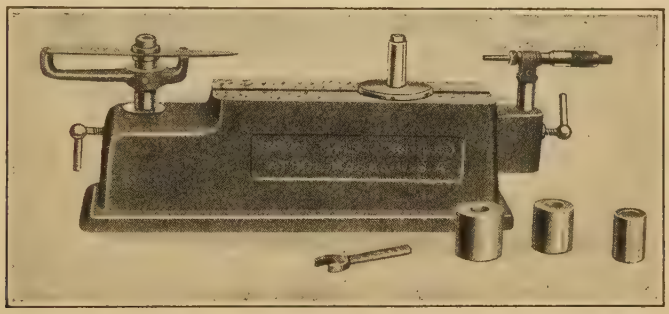


Fig. 37. Fixture for Testing Concentricity of Periphery and Bore of Milling Cutters and Position of Face of Cutter Teeth of the Radial Type

of the work, is shown in Fig. 37. This fixture also determines, by means of a separate indicating needle, whether or not the teeth are radial. It consists of a base carrying an adjustable stud on which the cutter to be tested is held, bushings being supplied for fitting different sizes of holes in the cutters. The cutter is then brought up to the micrometer spindle and rotated to determine if all of the teeth are of the same height. The work is then shifted over to the indicating pointer, and this is brought in contact with the face of the teeth. If the teeth are radial with the center, the indicating mark on the opposite end of the pointer registers zero on the arm of the fixture.

A fixture which can be applied to milling cutters or hobs having

under-cut teeth is shown in Fig. 38. This gage indicates if the cutter is true; that is, if the teeth are equidistant from the center, and if the proper amount of under-cut is provided. The faces of the teeth are tested by means of a finger mounted on a slide. Readings can be taken from the scale at the left-hand end of the gage, which is graduated in fiftieths of an inch. The proper readings can be obtained by multiplying the radius of the cutter by the following constant for different angles of face, or under-cut:

Angle of Face or Under-cut, Degrees	Constant, Inches	Angle of Face or Under-cut, Degrees	Constant, Inches
5	0.087	20	0.342
10	0.174	25	0.423
15	0.259	.....	.....

Fig. 39 shows how this reading is obtained and also how the gage is used. For testing, if the faces of the teeth are radial, the slide on the fixture in Fig. 38 is brought to zero, and con-

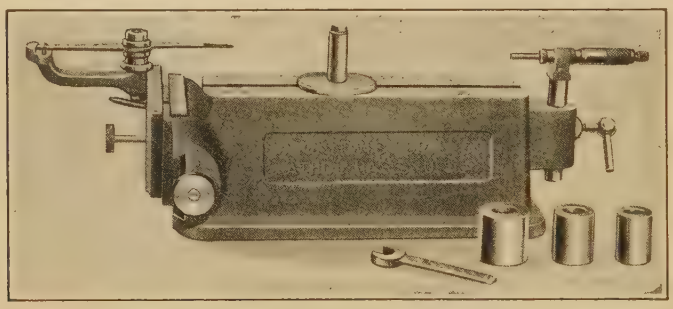


Fig. 38. Similar Device to that shown in Fig. 37, for Testing Under-cut on Teeth of Milling Cutters and Hobs

sequently does not have any lateral movement. When the teeth are under-cut, however, the fixture is moved over the amount given by multiplying the constant by the radius of the cutter, and the pointer should then indicate zero if the cutter is correct. The opposite end of the fixture carries a micrometer test instrument for determining whether or not the points of

the teeth are equidistant from the center; in other words, if the hole and points of the teeth are concentric with each other.

Concentricity Gage for High-explosive Shells. — Fig. 40 shows a simple type of indicating concentricity gage for inspecting

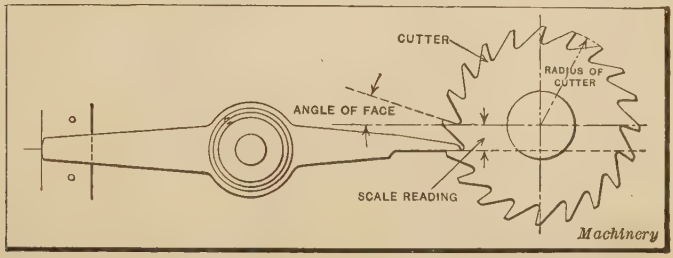


Fig. 39. Diagram illustrating how Indicating Lever for Under-cut Teeth is set Off Center on Fixture shown in Fig. 38

high-explosive shells. This consists of a base *A* carrying an arbor *B* on which there are two bushings, both slightly tapered.

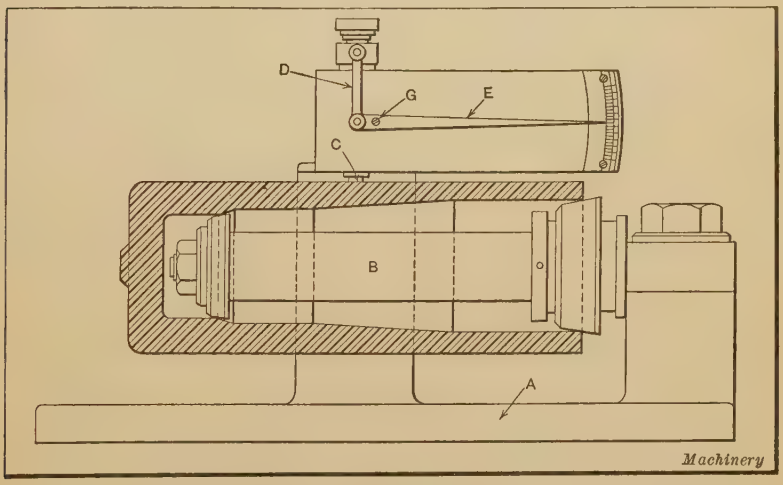


Fig. 40. Simple Type of Indicating Concentricity Gage for High-explosive Shells

One bushing fits the hole near the bottom and the other at the open end or nose. The shell is simply held on the fixture by hand and rotated to determine whether or not the exterior surface is concentric with the bore. The concentricity of these

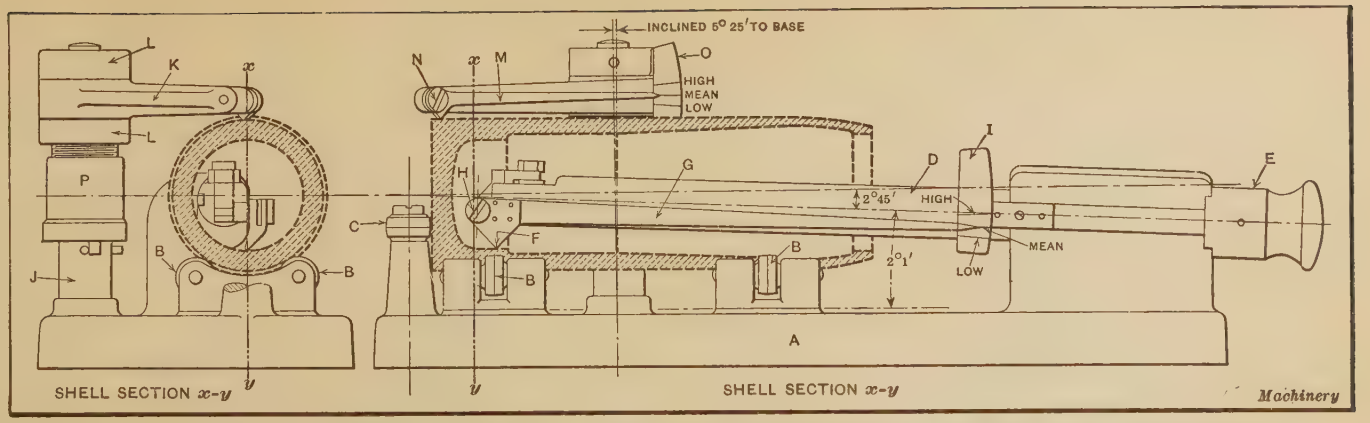


Fig. 41. Gage for Determining Concentricity of Powder Pocket and Exterior Surface near Base End of Shrapnel Shells

two surfaces is determined by means of a multiplying lever arrangement, consisting of a movable plunger *C*, link *D*, and pointer *E*. Pointer *E* is fulcrumed at the point *G*, giving a multiplying movement of 12 to 1. In other words, a variation of 0.001 inch moves the extreme end of the pointer 0.012 inch.

Gage for Testing Concentricity of Shrapnel Shells. — A great many gages for shell work have been designed during the past year. An indicating concentricity gage for shrapnel shells is shown in Fig. 41. This differs from that in Fig. 40 in that the shell is supported from the exterior instead of from the interior surface. Base *A* is provided with several bosses for holding the indicating lever mechanisms, as well as with the rollers *B* and *C* for supporting and positioning the shell. Rollers *B* are so located that the axis of the

shell is inclined at an angle to the base of the fixture. This is done to keep the base of the shell constantly in contact with the roller *C*, and thus locate it properly in relation to the contact point of the indicating levers. The two points on the shell which are tested for concentricity are the bore of the powder pocket and the exterior surface of the shell close to the base.

The indicating mechanism which determines the concentricity of the powder pocket consists of a rod *D* to which a handle *E* is attached, provided with a flattened end fitting in the corresponding slot in the boss on the fixture. The indicating lever *G* is fulcrumed at the point *H* and swings over the arc *I* provided with three points — mean, low, and high. The indicating device for the exterior of the shell is held on a post *J* and consists of an arm *K* held between two adjusting nuts *L*. The indicating lever *M* is fulcrumed at the point *N* and swings over the scale *O*, having marks, mean, low, and high. In order to locate the point of the fulcrum lever *M* directly in line with the vertical axis of the shell at its highest point, the bushing *P* is provided, carrying a pin which comes in contact with stop-pins in the rod *J*.

Inspecting Cams on Gas Engine Camshaft. — A class of gaging which requires accurate and careful inspection methods is the testing of cams on gas engine camshafts. These cams must be tested for shape, lift, and angularity of position. The requirements are that the profile of the cam between the opening and closing points must fit a contour gage having limits of ±0.003 inch. When the concentric part of the cam is within the limit of tolerance, which is 0.001 inch, the body plus the lift must be correct to within 0.003 inch. The arc of the opening and closing points on the cam must be correct to within ±1½ degree. The relative positions of the opening and closing points on all cams must be correct to within ±1 degree, and this error must not be cumulative. The usual clearance provided between the top of the valve-lifter and the lower surface of the valve-stem is from 0.003 to 0.010 inch.

A simple method of gaging this work is shown in Fig. 42.

This fixture is used for testing the position of the cams on an integral four-cylinder engine camshaft. The fixture comprises a bed-plate *A* on which three brackets *B*, *C*, and *D* are held. Brackets *B* and *C* are used as supports only, and are provided with hinged caps held by thumb-screws to facilitate the insertion and removal of the camshaft. The bracket *D* carries a special chuck for gripping the work and is furnished with an index plate *E* which has eight notches to correspond with the number and position of the cams on the shaft. This disk is located in the various positions by a tapered plunger that is

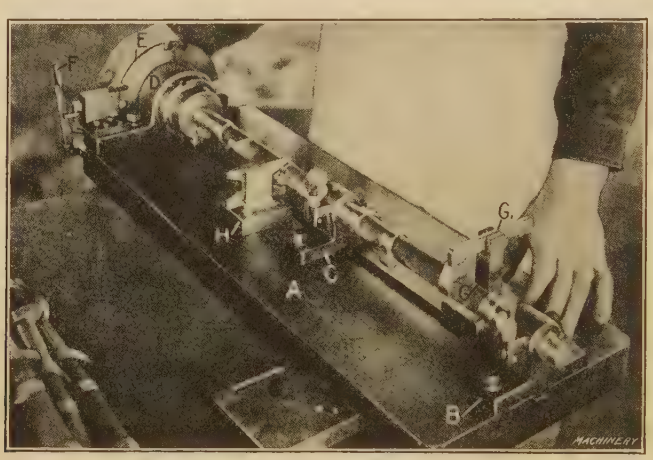


Fig. 42. Simple Type of Gas Engine Cam Testing Fixture for Determining Shape of Cam, Angularity, Lift, Etc.

held in contact with the disk by a spring and is removed by the handle *F* to index the disk. The highest point of the cam is tested by the T-gage *G*, which has "go" and "not go" ends on the bar G_1. The angularity and shape of the cams are tested by the V-gage *H*, which is provided with knife-edge points and is used in connection with the indexing disk. This gage also has "go" and "not go" V-grooves, which are made to the exact shape desired. The brackets on this gaging fixture are all located from a central groove in the bed which keeps them in correct alignment.

Another method which employs a dial test indicator is shown

in Fig. 43. This device is of comparatively simple construction and consists of a base A sufficiently heavy to stand firmly, and a vertical support B held in the base by means of screws. The upper end of the support is drilled and reamed to receive the shank of the dial indicator I, and is split and provided with a screw to clamp it. The indicator point P is made in the form of a spherical segment the radius r of which is one-half the diameter of the cam roller. The center line of the indicator must be in the same position in relation to the camshaft that the roller is in the gasoline engine, which in this case is on the

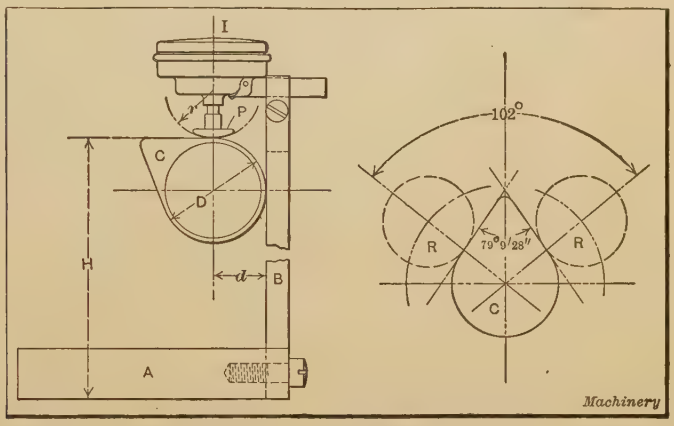


Fig. 43. Method of using Dial Test Indicator for Inspecting Gas Engine Cams

center line of the camshaft. The distance d is then one-half D and the height H is such as to give a good contact between point P and cam C and allow the full limit of the indicator movement.

When in use, the camshaft is provided with a dog and mounted between the index centers of a suitable fixture. The first step then is to find the center of the keyway for the camshaft gear, as the cams are generally laid out with reference to a keyway. Assuming that the cam is of the shape shown in the illustration, and that the center coincides with the center line of the keyway, and also that the opening and closing points are in the position occupied by the cam rollers R represented by the

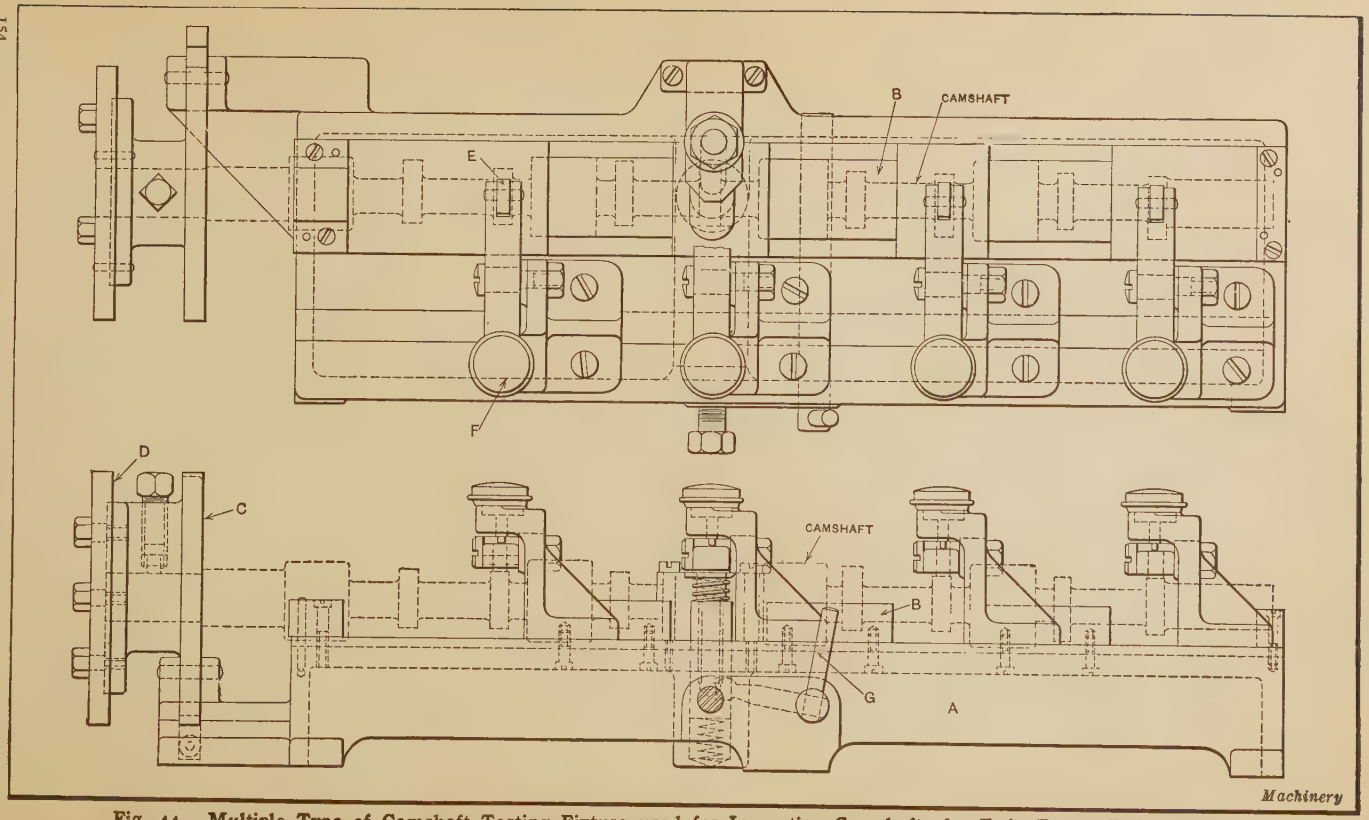


Fig. 44. Multiple Type of Camshaft Testing Fixture used for Inspecting Camshafts for Twin Four-cylinder Engines

dotted circles to the right of the illustration, the actual opening and closing points are then one-half 102 degrees, or 51 degrees in advance and 51 degrees back of the starting point. Now, with the indicator set on the dwell of the cam allowing for a rise of 0.003 inch — "the clearance under the valve-stem" below zero — and with the indicator in the position shown, the camshaft is indexed to the correct angle. If the work has been accurately done, the indicator needle should just begin to rise at the 51-degree angle; if not, it will rise either too soon or too late, and the amount of error is read off on the index circle of the indicator. The relation of all the other cams to the keyway is tested in a similar manner, taking all the opening points in their regular order, and then all the closing points. The amount of error sometimes found in spite of very careful work is surprising, and this method of testing insures a high degree of accuracy.

Multiple Indicating Camshaft Gage. — A multiple indicating camshaft gage for testing the exhaust and inlet cams for twin four- or eight-cylinder engines is shown in Fig. 44. This consists of a fixture for holding the camshaft and indexing it while being tested, and brackets for carrying four dial indicators, so that four cams can be tested at the same setting of the camshaft. For the other four sets of cams, the camshaft is shifted and the testing operation repeated. The fixture consists principally of a base *A*, to which four V-blocks *B* are attached. The bearings on the camshaft rest in these V-blocks. After the camshaft is held in the V-block and located in the correct position, a double index plate *C* and *D* is fastened to the end of the shaft in order to give the correct angular position of the camshaft when testing the location of the opening and closing points on the cams. Four cams, as previously mentioned, are tested at a time. The index plate is moved into the position desired and the reading is transmitted from the cams by the rollers *E* to the needle of the indicators *F*.

The reading on the dial indicator is taken when the cam has raised the roller 0.005 inch, thus allowing for the clearance between the end of the push-rod and the valve-stem. As soon

as readings have been taken from four cams and they are found correct, the lever *G* is operated, which releases the single clamp that holds the camshaft in position in the fixture, bearing down with sufficient pressure to prevent it from shifting, but at the same time allowing it to be rotated by means of the index plate. The camshaft is then shifted along the fixture to bring the remaining four cams into position under the indicators, and a similar procedure followed. The fixture is so constructed that the index plate moves with the camshaft

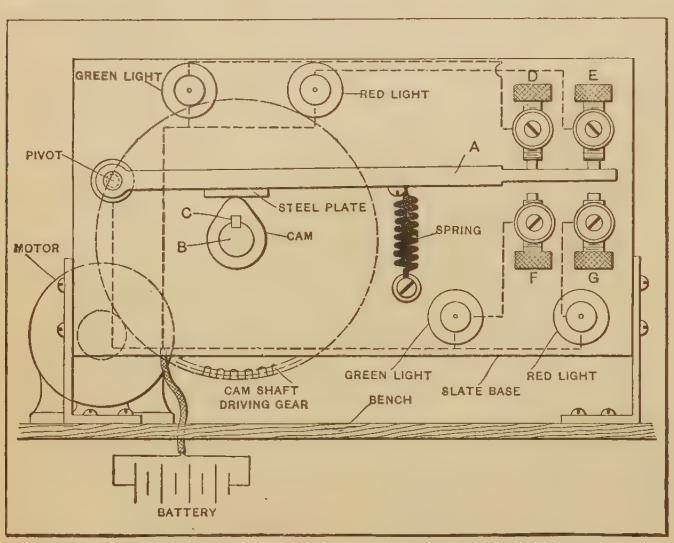


Fig. 45. Electrical Device for Inspecting Gas Engine Cams of Detachable Type

when it is shifted over to bring the second set of cams into the testing position. By means of this gage, the testing of camshafts is greatly simplified in that four readings can be taken at one setting.

Electrical Camshaft Gage. — An electric device for testing individual cams is shown in Fig. 45. This gage consists principally of a pivoted arm *A* that is raised or lowered by the thrust of the cam being tested and is held in contact with the cam by a helical spring. The cam is carried on the shaft *B*, which is provided with a key *C*, the cam being slowly rotated

by means of a small motor located behind the slate base to which the entire mechanism is attached. Connection is made with an electric battery in such a manner that, when the cam raises and lowers the arm *A*, it closes the electric circuit by making contact with the adjusting screws *D*, *E*, *F*, and *G*, respectively. If the throw of the cam is too slight, no contact will be made with either of the adjusting screws *D* and *E*; if the throw is as it should be, contact will be made with the screw *D*, and the green lamp on the top of the board will flash. If the throw is too great, contact will be made with both screws *D* and *E*, resulting in the flashing of both the red and the green lamps. In the same manner, the lamps at the bottom of the board are flashed; if the diameter of the cam is too great, neither light flashes; if correct, the green light shows; and, if too small, both the green and red lights show. The contact screws are made from brass carrying a copper contact point which is pressed out by means of a brass spring. This device is adjusted by means of a master cam which has been measured by hand and found to be correct.

Fig. 46. Special Type of Indicating Gage for Inspecting Interrupter Cams for Electric Starter

Device for Testing Electric Starter Ignition Cams. — Fig. 46 shows an application of the indicating dial type of gage in conjunction with a multiplying lever for testing ignition cams for "Delco" electric starters. The indicator used gives readings

to 0.0001 inch. The gage is rigidly built and consists of a base *A* into which a stand *B* is screwed that carries the measuring table *C* provided with a split box at the rear through which passes the post supporting the multiplying lever arrangement. The dial test indicator *D* is fastened to the rear bracket and is operated by a multiplying lever *E*. This is fulcrumed on adjustable pointer screws *F* and is provided with a boss at its lower surface in which a plunger *G* fits. This plunger is adjusted by a screw *H* which, in turn, is clamped by a screw *I*. In this case, the cam to be gaged is held on a stud *J* and is brought into contact with a locating point *K*. Previous to testing the work, the gage is set at zero by means of a master. The limits on this work are ±0.0005 inch.

Ordinate System of Gaging. — As explained in Chapter IV, irregular-shaped parts are generally gaged by means of profile templets, the work being inspected by holding it in contact with the templet and up to the light. A very small variation in the work from the gage can be detected by the rays of light between the two pieces, but there is no definite means of determining just what this variation is. Consequently, the templet system is not satisfactory for interchangeable manufacture, as the discrepancies in the work are not measurable. The type of profile gage used is governed largely by the shape and character of the work. In gaging approximately cylindrical work, a profile gage called a "receiver gage" is generally employed. In this case, the gage is bored, reamed, and lapped to the shape of the work and is then slabbed off so that the hole in the gage is exposed; then when the work is inserted, its outline can be compared with that of the gage. The most common form of templet is made from sheet steel and is filed and ground on the measuring side to a knife-edge similar to that used on a straightedge. When the work to be measured has several shoulders or irregularities of outline, it is necessary that the gage be held parallel with the axis of the work. There are other objections to the templet system, and in up-to-date manufacturing plants templets are used as sparingly as possible.

By the ordinate system of gaging, a piece of irregular outline is gaged at all the principal points for the desired measurements by means of either one of two systems. One system employs the flush-pin principle and the other the dial test indicator. The system used depends upon the number of surfaces to be gaged and the convenience with which these surfaces can be approached. Fig. 47 shows a simple method of gaging a piece of irregular outline. In this case, the flush-pin principle can be adopted because of the comparatively

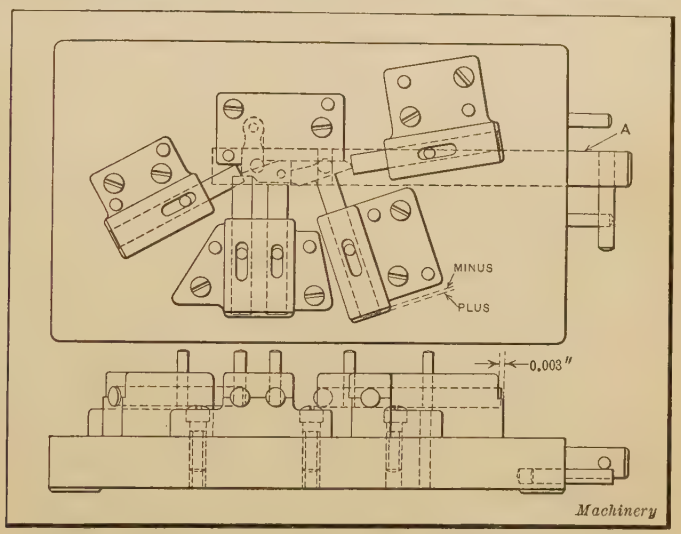


Fig. 47. Flush-pin Type of Gage for Inspecting Work on the Ordinate Principle

simple outline of the piece. These flush-pins are held in separate blocks fastened to a base, and the axis of the flush-pin is located at right angles to the surface to be gaged.

The rear end of the bracket carrying the flush-pin is provided with a plus and minus limit step. The flush-pins are pushed back to insert the work in the holder, and are then pushed forward to ascertain whether or not the work has been machined properly. The test consists in comparing, by the sense of touch, the positions of the ends of the flush-pins with relation to the steps on the rear ends of the holders. A simple

ejecting mechanism is used in connection with this gage; it consists of a rod *A* passing through the body of the plate and carrying two eccentrics. These work against pins held in the base that are forced upward by the eccentrics to eject the work from the dowel-pins on which it is held. Two pins in the end of the gage block act as stopping points for this rod.

Another type of gage working on the ordinate principle is shown in Fig. 48. In this case, the dial test indicator principle is employed, because the points that must be measured are not accessible with the flush-pin type. The construction of

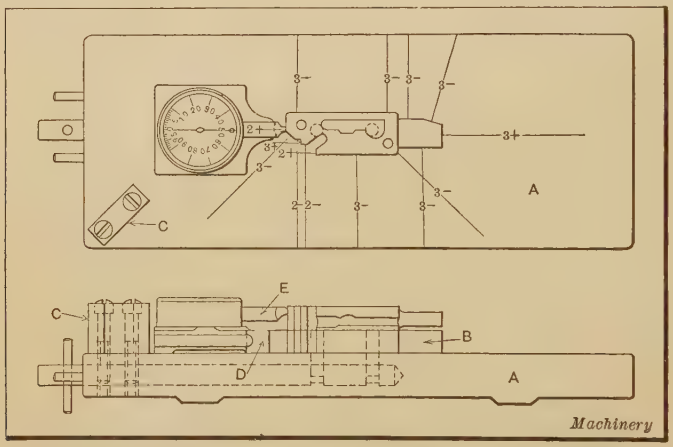


Fig. 48. Dial Indicator for inspecting Irregular Work on the Ordinate Principle

this gage is comparatively simple; it consists chiefly of a base *A* carrying a hardened and lapped master block *B* which is of the same shape as the work and is hardened, ground and lapped to the mean dimensions of the work. This block is provided with close-fitting dowel-pins which are made to fit the locating holes in the work to be gaged. In the lower left-hand corner of the gage is a block *C*, which is used for setting the block *D* and spindle *E* of the dial test indicator in line with each other. The surface of this block is hardened, ground and lapped, and is at right angles to the surface of the plate. Lines are drawn from the points where the gaging is to be done,

and opposite these lines are numbers. These numbers indicate the limits in thousandths of an inch provided on the work. For instance, (3 −) means that at this point the piece can be 0.003 inch less or smaller than the master by which it is being compared.

In using this gage, the block carrying the dial test indicator is swung around and the dial test indicator spindle and

Fig. 49. Indicating Gage for Testing Pressure of Gas Engine Valve Lifter Springs

measuring end of the block are brought in contact with the setting block *C*. The bezel of the dial test indicator is then rotated so that the needle points to zero. The gage is then swung around and brought in contact with the work. Index points are marked on the rear and front ends of the block *D* so that these are brought in line with lines on the plate *A*.

Then the block *D* is brought in contact with the master, and the spindle of the dial test indicator in contact with the work, the resulting readings being taken off on the indicator. The indicator and block which are fastened to each other can be moved around to any point on the work and the variations between the work and the master can be read off in thousandths of an inch. The advantage of this system over the templet system is evident, in that it gives a direct reading and indicates to the inspector just how many thousandths of an inch the work varies from the required size.

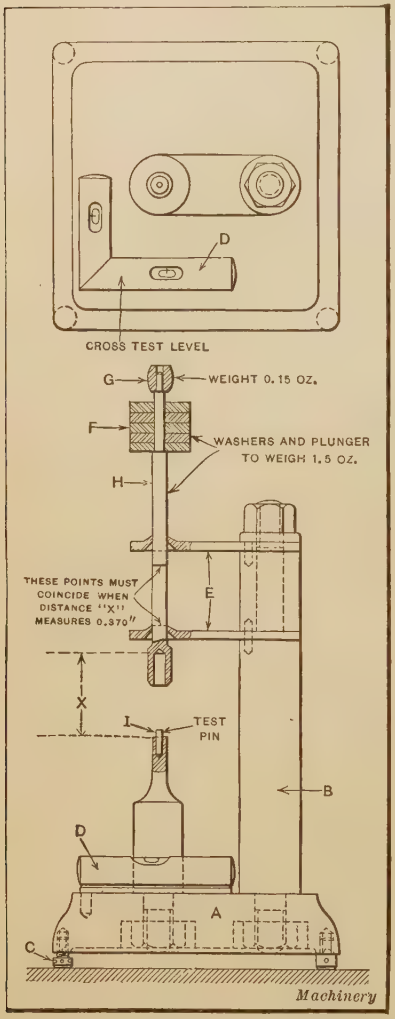


Fig. 50. Indicating Gage for Testing Compressive Strength of Springs used in Combination Time and Percussion Fuses

Dial Indicators for Testing Pressure. — The dial indicator is used to a large extent for testing pressure in the inspection of springs that must be capable of exerting a required pressure when compressed a certain amount. The application of the dial indicator to this work is shown in Fig. 49. This illustration shows a special fixture used in testing the pressure exerted by conical valve springs for gas engines. The fixture consists principally of a regular scale dial, which is attached to a base *A* having an upright *B*. This upright carries a spindle which is operated

by a rack and pinion through the turnstile *C*, the distance that the spring is compressed being determined by the stop *D*, which comes in contact with a pin on the top of the fixture. The spring being tested is compressed about $1\frac{1}{2}$ inch — the compression it has in the gas engine — and must show a pressure of 58 pounds on the dial.

Device for Testing Time Fuse Percussion Restraining Springs. — A much more delicate instrument than that illustrated in Fig. 49 is shown in Fig. 50. In this case, the device is used for testing the pressure of percussion restraining springs used in combination time and percussion fuses. It consists of a base *A* carrying an upright *B*; the base *A* rests on four feet *C*, which are capable of being adjusted so that the instrument can be set "parallel," this being determined by means of the cross-level *D*. Post *B* carries two plates *E*, which support the spindle carrying the washers *F* and *G*. These plates are countersunk so that only a knife-edge bearing is provided for contact with the plunger. The total weight of washers *F* and plunger *H* is 1.5 ounce; the "limit weight" *G* is 0.15 ounce. The spring to be tested is placed on test pin *I*, the spindle *H* meanwhile being held up by hand. The spindle is then allowed to compress the spring, and if it is correct, the points marked must coincide when the distance *X* is 0.370 inch. If the weight of *F* and the spindle is not sufficient to give this reading, the limit weight *G* is added; if this makes the distance *X* correct, then the spring is satisfactory; if not, it is too stiff. If the distance *X* is less than 0.370 inch when weight *G* is not on the spindle, then the spring is too weak.

Indicating Gage depending upon the Sense of Hearing. — As has been previously mentioned, indicating gages depend upon the sense of touch, sight, and hearing for their operation. Those depending upon the sense of hearing are generally of the electrical type, and an example of a gage employing this principle is shown in Fig. 51. This gage is employed for testing the closing pressure of piston rings. Piston rings have been tested for closing pressure by many other devices, all of which have been more or less satisfactory. It is generally

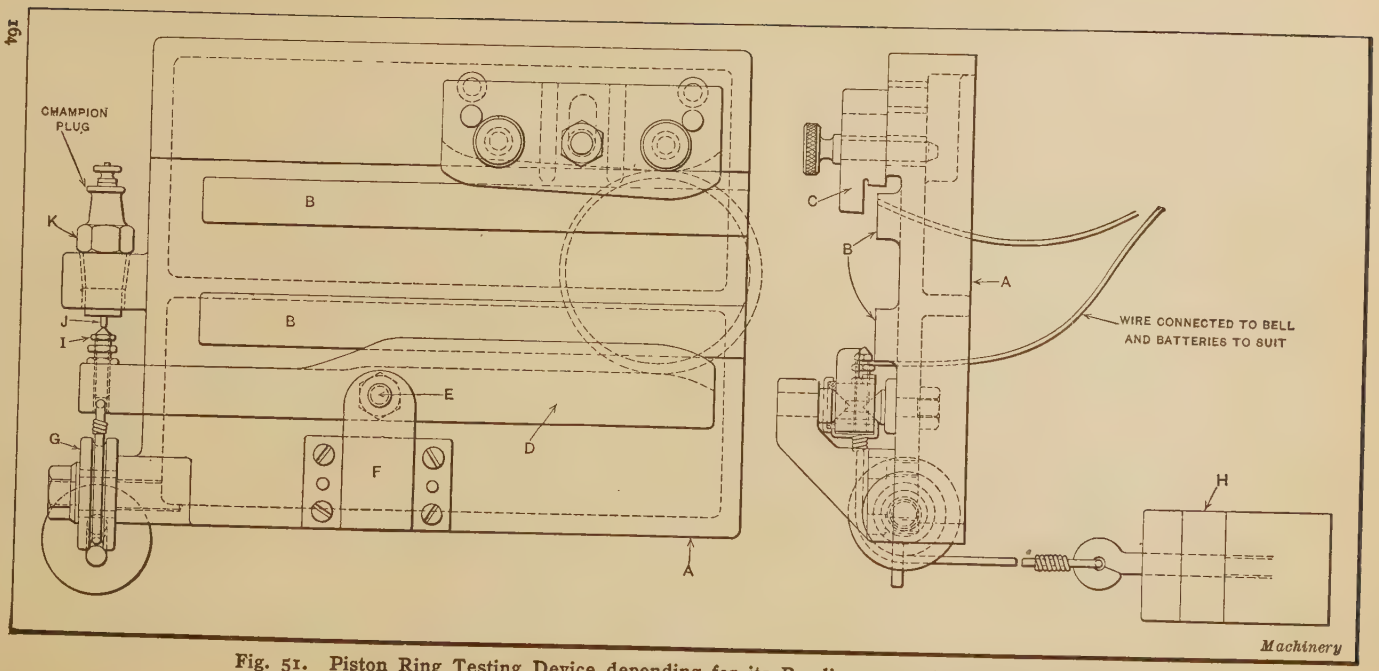


Fig. 51. Piston Ring Testing Device depending for its Reading upon the Sense of Hearing

known that a piston ring which does not possess the required amount of tension does not lie in close touch with the walls of the cylinder all around, and hence gas is allowed to leak past and compression is lost. It is, therefore, desirable to know if the rings have sufficient tension before they are inserted in the piston, and the gage in Fig. 51 determines this satisfactorily.

The gage has a cast-iron plate *A* machined on its top surface to provide two ribs *B* that are nicely finished so that the rings can be slipped along them without undue friction. Fastened to one side of the fixture is a bracket *C*, which is machined out on one edge, providing a step that is of a slightly greater height than the width of the piston ring to be tested. Held on the other side of the cast-iron plate is a lever *D*, which is fulcrumed at the point *E* by two cone-pointed screws in the bracket *F*. At one end of the fixture, pulley *G* is attached, and running over this is a wire rope which carries the weight *H*; the size of the weight depends upon the size of piston ring being tested. This wire rope is attached to the rear end of lever *D*, which carries a contact point *I*. This contact point makes contact with the point *J* of the "Champion" spark plug *K* when the piston ring is of the desired tension. Plug *K* is connected by suitable wiring to a bell and battery in the box under plate *A*.

When using the gage, the inspector lays the ring flat on the testing surface of the plate and pulls it toward him between the fixed and movable strips *C* and *D*, respectively, with the split or saw cut exactly in the center. In pulling the ring through the fixture, if the pressure is sufficient to overcome the resistance of weight *H*, which on the Ford piston ring is 18 pounds, electrical contact is made between points *I* and *J*, and the bell in the box of the fixture is rung. If the inspector pulls the ring through the fixture without the bell ringing, then the ring does not come up to the required tension, and is consequently rejected. When this fixture was adopted in one plant, it was found that previous methods had been inaccurate, and anywhere from 20 to 50 per cent of the rings

formerly made proved to be failures. Changes in manufacturing methods, however, reduced the number of failures from 5 to 10 per cent.

Gaging and Inspecting Balls and Ball Bearings. — Aside from the manufacture of rifles and similar interchangeable work, there is probably no industry in which gaging and inspection methods are developed to a higher degree of perfection than in the manufacture of balls and ball bearings. As a rule, this industry is divided; that is, one manufacturer makes the balls and another the bearings. There are some manufacturers who make the entire product, but this is the exception rather than the rule. No other industry makes more extensive use of indicating gages than the ball and ball bearing industry, and, in the following, attention will be given to the types of gages used for this work.

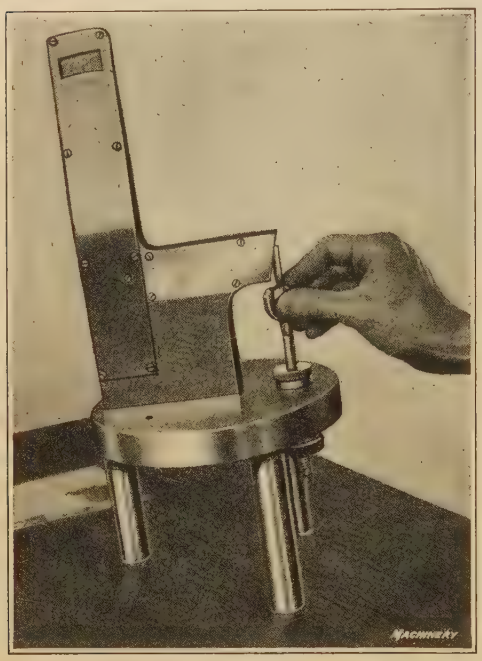


Fig. 52. Indicating Gage for Testing Balls during Process of Manufacture

Gaging and Inspecting Balls. — In the gaging and inspection of balls, there are two main points that must be considered: First, the ball must be spherical within certain limits, and, second, it must be made to a definite diameter, also within limits. The manufacturing limits to which the balls are made depend entirely upon the use to which the balls are put. For high-grade balls they must be held to within a limit of 0.00005 inch of being perfect spheres, and must not vary more than

0.00005 inch in diameter. For bicycles, hardware, and similar work, the manufacturing limits can be considerably wider. In the following, however, attention will be directed particularly to the gages used in making high-grade balls.

During the process of manufacture, the balls are gaged to see that the grinding or lapping machines are working properly. Figs. 52 and 53 show a special gage developed by the Hoover Steel Ball Co., of Ann Arbor, Mich., for this work. Referring to Fig. 53, which shows the construction of the gage more clearly, it will be noticed that it is of the adjustable type and is provided with two anvils, one of which is adjusted by means of a screw held in place by clamping nuts. The gage consists principally of plate *A* mounted on three feet, the rear one of which is shorter than the other two, so that the gage is inclined at a slight angle. The ball to be gaged is shown held in the nest *B*, and the gage is so inclined that the ball always rests in the rear of this nest.

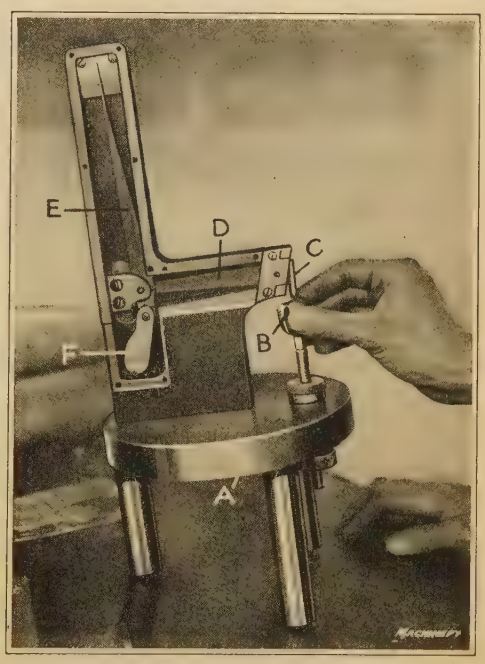


Fig. 53. Indicating Gage shown in Fig. 52 with Plate removed to show Constructional Features

The upper and lower anvils are provided with diamond gaging points held in brass holders. These diamonds are so mounted that a flat face is presented to the ball surface to be gaged. The multiplying lever principle is used here in the ratio of 150 to 1, so that, for variations of 0.0001 inch in the ball, the top point of needle *E* would move over the arc a dis-

tance of 0.015 inch. The construction of this indicating lever mechanism is as follows: Lever *D* is connected to anvil *C* and meshes with lever *E* through a rack tooth. There are no springs in this gage, and the upper anvil is kept in contact with the work by means of a weight *F* attached to the indicating needle *E*. By means of this gage, it is possible to determine rapidly if the balls are being ground out of round or

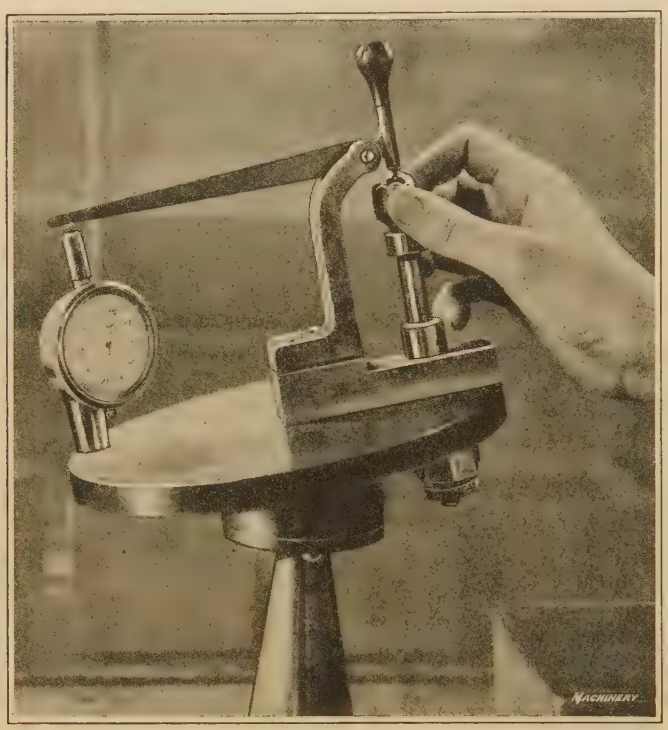


Fig. 54. Indicating Gage of Dial Type in Combination with Multiplying Lever for Testing Balls over $\frac{5}{8}$ Inch in Diameter

under diameter when in the rough state. While the wear on the diamonds is very slight, it is nevertheless necessary to be certain that the instrument is measuring correctly, and at certain intervals the indicating needle is set by means of a master ball. The adjusting screw holding the lower anvil is then adjusted the required amount.

Indicating Gage for Inspecting Finished Balls. — After the balls come from the grinding and lapping departments, the first inspection consists in looking them over to see that they are free from pits, scale, bands, dents, tool marks, etc. This is done on the smaller sizes of balls (up to $\frac{5}{8}$ inch in diameter) by rolling the balls on a glass plate. A ball that is not perfectly spherical will not roll straight, but will wobble from side to side. Balls over $\frac{5}{8}$ inch in diameter are inspected by means of the indicating gage shown in Fig. 54. This device consists of a dial gage combined with a multiplying lever mounted on a plate held on a stand which is set at an angle so that the ball

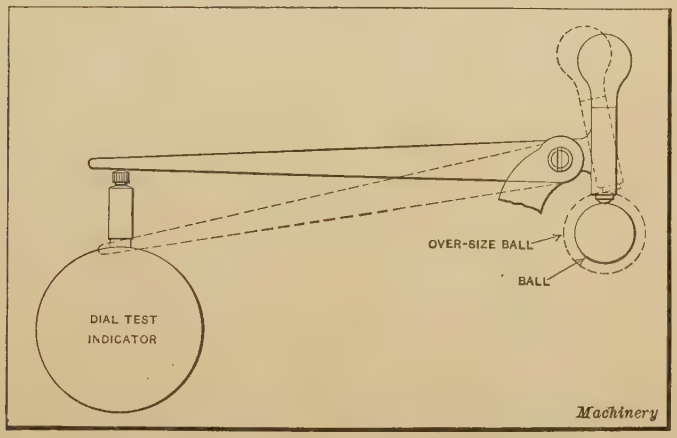


Fig. 55. Diagram illustrating Limitations of Multiplying Lever Type of Gage

being gaged always lies at the back surface of the pocket in which it is retained. The lower and upper anvils carry black diamonds, the flat surfaces of which bear upon the ball. The multiplying lever is in the ratio of 10 to 1, and as the indicator normally reads to 0.001 inch, this multiplication makes it possible to obtain readings to 0.0001 inch. The limit on the ball is 0.00005 inch both for roundness and diameter, so that the maximum movement of the needle for satisfactory balls would be not more than one-half the amount between any two marks on the dial.

In multiplying lever gages made on this principle, it will

be seen, by referring to Fig. 55, that very wide variations in diameter cannot be accurately indicated. The reason for this is that the length of the arm of the multiplying lever changes as the measuring point is moved up or down. Consequently, it is essential that a master ball be used for setting this gage

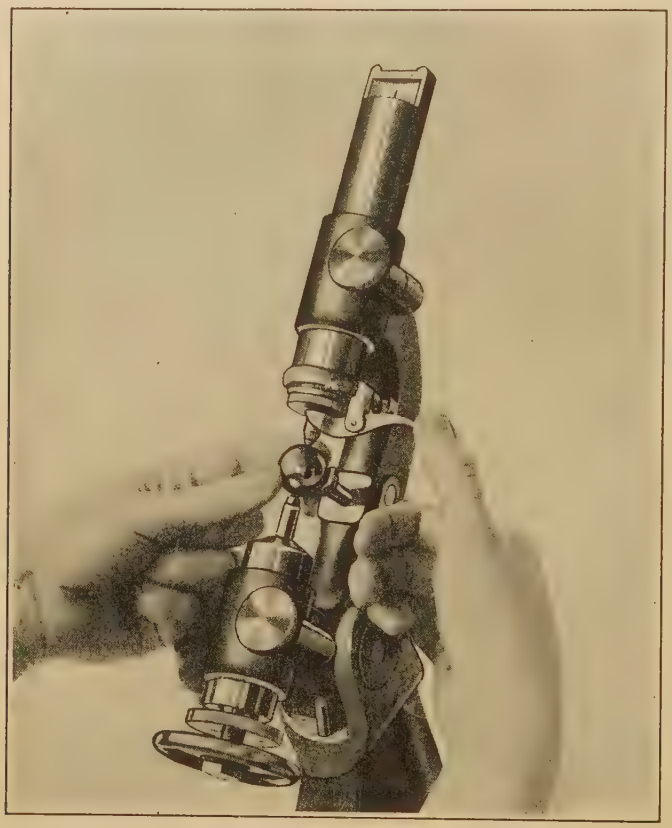


Fig. 56. Hirth Minimeter used for Testing Diameter of Finished Balls

for each size of ball to be gaged, and then that the gage be used only as a means of comparison and not as a direct measuring instrument. Girls operating these instruments can gage 10,000 balls in ten hours, or 1000 balls an hour, and determine whether the ball is out of round, within the limits for diameter, or if

it has any other imperfections which have passed the notice of the previous inspectors.

Hirth Minimeter for Gaging Balls. — Fig. 56 shows a Hirth minimeter for inspecting balls for accuracy of diameter and spherical form. It consists of a special stand carrying a lower anvil which is adjustable as shown, a support for the ball to locate it so that its axis comes in line with the upper and lower anvils, and an arm in which the minimeter proper is retained. The top measuring anvil of the minimeter is lifted by means of the finger, as shown, and when the ball is inserted all external pressure is removed. This instrument is constructed so that readings as fine as 0.00005 inch are obtainable.

Automatic Ball Gaging Machines. — High-grade balls under $\frac{5}{8}$ inch in diameter are gaged for accuracy of diameter by automatic ball gaging machines, two types of which are shown in Figs. 57 and 58. The machine shown in Fig. 57 is used for gaging balls up to $\frac{3}{8}$ inch in diameter and comprises a hopper for holding the balls, and a slide through which they roll when being gaged. The measuring portions of this slide consist of two straightedges, the space between the edges of which gradually increases in width as the slide extends from the hopper. Passing beneath the hopper is a slide which is agitated by a rack and segment gear, operated by an eccentric motion. The balls to be gaged are dumped into hopper *A* and carried forward to the delivery spout by means of a slide *B*. Slide *B* carries one ball forward at a time, drops it through spout *C* and into slide *D*. Here the distance between the two slides is about 0.005 inch smaller than the smallest diameter of the balls to be gaged. The balls then roll along between slides *D* until they come to the straightedges *E*. These straightedges are set so that they form a slightly tapered slot or opening. The angle or taper to which these straightedges is set is determined entirely by the limits required on the balls. If the balls must be held within very close limits, then the amount of variation in the taper of the straightedges is slight. Sometimes they are set so that a difference of 0.005 inch in diameter will be measured from one end to the other. As the balls roll down

these slides due to the action of gravity, the angle to which they are set being about 20 degrees from the plane of the table, they drop through the slide at the point where the distance between the two straightedges is slightly greater than the diam-

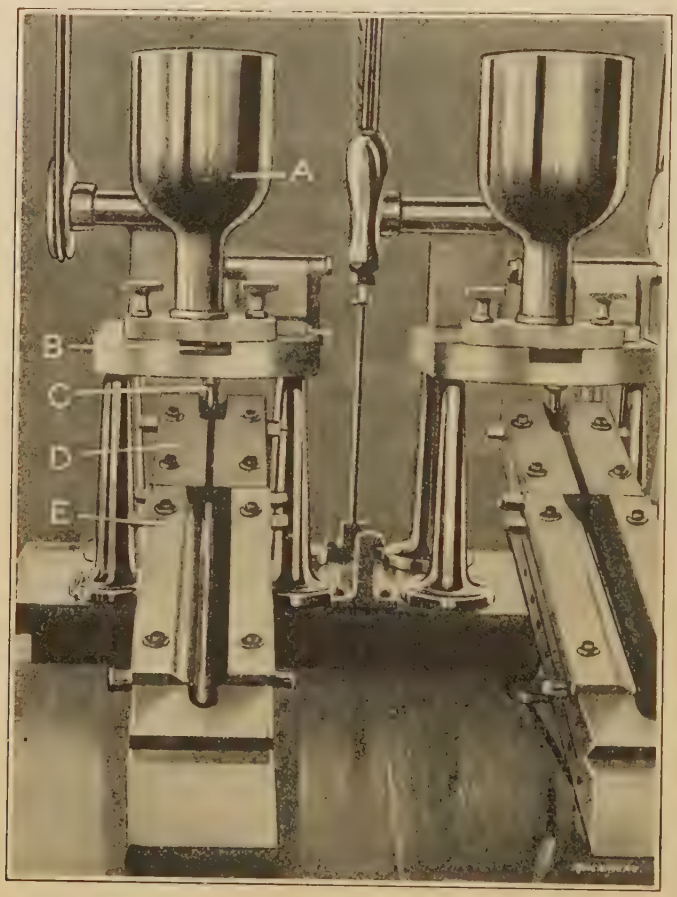


Fig. 57. Automatic Ball Gaging Machine for Inspecting Balls up to $\frac{3}{8}$ Inch in Diameter

eter of the ball. As they drop through, they are separated by tubes which enter the various drawers in the cabinet located beneath the table top. When these drawers are full, they are removed and the balls taken out and put in proper boxes, according to the grading determined by the machine.

Another type of automatic ball gaging machine is shown in Fig. 58. This device is used for gaging balls up to $\frac{5}{8}$ inch in diameter. In this case, the slides are set almost parallel with the table, and the balls are carried between the straightedges

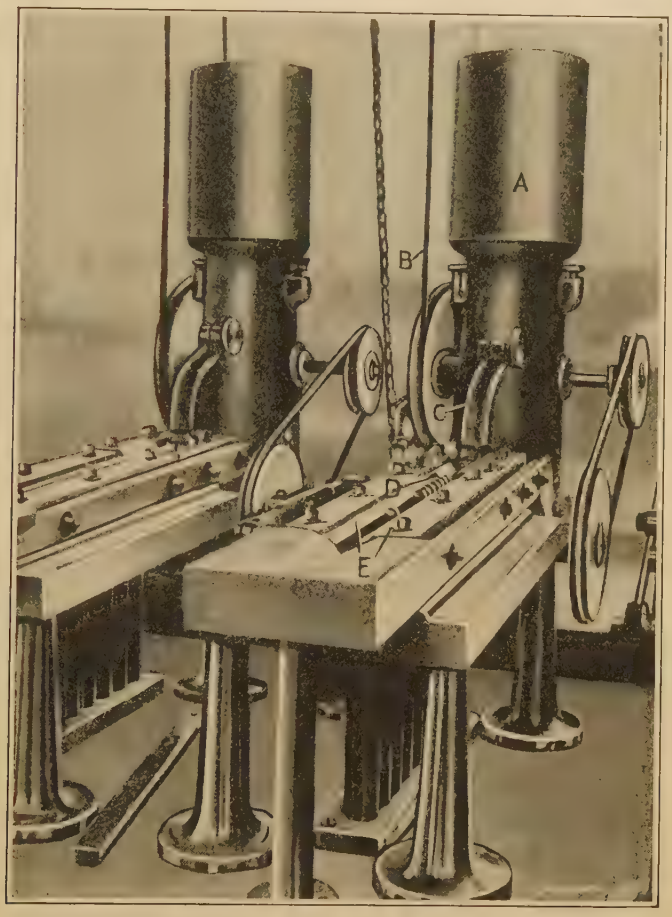
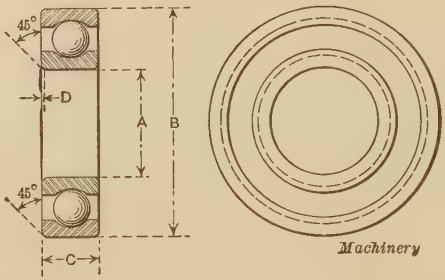


Fig. 58. Automatic Ball Gaging Machine for Inspecting Balls up to $\frac{5}{8}$ Inch in Diameter

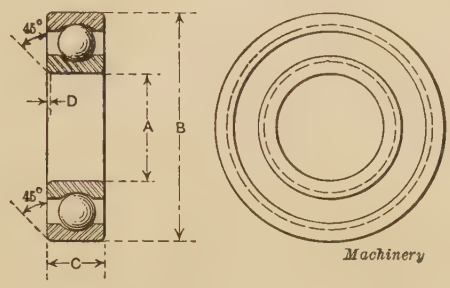
by means of an agitator which comes up and lifts them from the surface of the straightedges. The top surface of the agitator is at an angle of about 5 degrees, and when the agitator rises the balls roll along it until they drop through between the

Table I. S. A. E. Standard Sizes and Tolerances for Ball Bearings (Light Series)



Ball Bearing Number	Bore of Inner Race Ring			Diameter of Outer Race Ring		
	Bore A, Inches	Tolerance, Inch		Diameter B, Inches	Tolerance, Inch	
		Plus	Minus		Plus	Minus
200	0.39370	0.0002	0.0004	1.18110	0	0.0006
201	0.47244	0.0002	0.0004	1.25984	0	0.0006
202	0.59055	0.0002	0.0004	1.37795	0	0.0006
203	0.66929	0.0002	0.0004	1.57481	0	0.0006
204	0.78740	0.0002	0.0004	1.85040	0	0.0006
205	0.98425	0.0002	0.0006	2.04725	0	0.0008
206	1.18110	0.0002	0.0006	2.44095	0	0.0008
207	1.37795	0.0002	0.0006	2.83465	0	0.0008
208	1.57481	0.0002	0.0006	3.14962	0	0.0008
209	1.77166	0.0002	0.0006	3.34647	0	0.0008
210	1.96851	0.0002	0.0006	3.54332	0	0.0008
211	2.16536	0.0002	0.0006	3.93702	0	0.0008
212	2.36221	0.0002	0.0006	4.33072	0	0.0008
213	2.55906	0.0002	0.0006	4.72443	0	0.0008
214	2.75591	0.0002	0.0006	4.92128	0	0.0008
215	2.95277	0.0002	0.0006	5.11813	0	0.0008
216	3.14962	0.0002	0.0006	5.51183	0	0.0008
217	3.34647	0.0002	0.0007	5.90554	0	0.0012
218	3.54332	0.0002	0.0007	6.29924	0	0.0012
219	3.74017	0.0002	0.0007	6.69294	0	0.0012
220	3.93702	0.0002	0.0007	7.08664	0	0.0012
221	4.13387	0.0002	0.0007	7.48035	0	0.0012
222	4.33072	0.0002	0.0007	7.87405	0	0.0012

Table II. S. A. E. Standard Sizes and Tolerances for Ball Bearings (Light Series)



Ball Bearing Number	Width of Both Race Rings			Corners D* on Outer Race and Bore of Inner Race, Inch	Eccentricity Tolerance, Inch	
	Width C, Inch	Tolerance, Inch			Inner Race Ring	Outer Race Ring
		Plus	Minus			
200	0.35433	0	0.0020	0.040	0.0008	0.0012
201	0.39370	0	0.0020	0.040	0.0008	0.0012
202	0.43307	0	0.0020	0.040	0.0008	0.0012
203	0.47244	0	0.0020	0.040	0.0008	0.0012
204	0.55118	0	0.0020	0.040	0.0008	0.0012
205	0.59055	0	0.0020	0.040	0.0008	0.0012
206	0.62992	0	0.0020	0.040	0.0008	0.0012
207	0.66929	0	0.0020	0.040	0.0008	0.0012
208	0.70866	0	0.0020	0.080	0.0008	0.0012
209	0.74803	0	0.0020	0.080	0.0010	0.0016
210	0.78740	0	0.0020	0.080	0.0010	0.0016
211	0.82677	0	0.0020	0.080	0.0010	0.0016
212	0.86614	0	0.0020	0.080	0.0010	0.0016
213	0.90551	0	0.0020	0.080	0.0010	0.0016
214	0.94488	0	0.0020	0.080	0.0010	0.0016
215	0.98425	0	0.0020	0.080	0.0010	0.0016
216	1.02362	0	0.0020	0.120	0.0012	0.0018
217	1.10236	0	0.0020	0.120	0.0012	0.0018
218	1.18110	0	0.0020	0.120	0.0012	0.0018
219	1.25984	0	0.0020	0.120	0.0012	0.0018
220	1.33858	0	0.0020	0.120	0.0012	0.0018
221	1.41732	0	0.0020	0.120	0.0012	0.0018
222	1.49607	0	0.0020	0.120	0.0012	0.0018

* A chamfer of 45 degrees ground true with the bore and outside diameter is recommended.

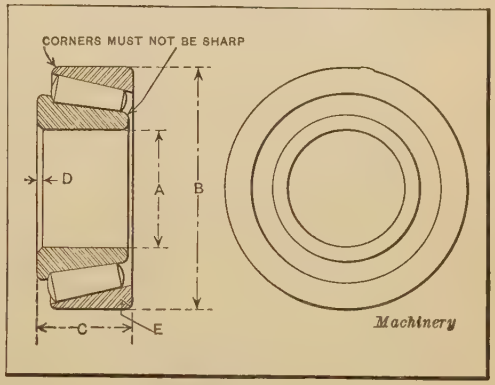
Table III. S. A. E. Standard Sizes and Tolerances for Roller Bearings (Narrow Series)

(See illustration on opposite page for notation)

Roller Bearing Number	Bore of Inner Cone			Diameter of Outer Cone			Width of Assembled Bearing			Minimum Chamfer D, Inch	Radius E, Inch	Eccentricity Tolerance, Inch	
	Bore A, Inches	Tolerance, Inch		Diameter B, Inches	Tolerance, Inch		Width C, Inches	Tolerance, Inch					
		Plus	Minus		Plus	Minus		Plus	Minus			Plus	Minus
RM-304	0.78740	0.0002	0.0006	2.04725	0	0.0008	7/8	0.020	0.020	0.040	0.040	0.0008	0.0012
RM-305	0.98425	0.0002	0.0006	2.44095	0	0.0008	1	0.020	0.020	0.040	0.040	0.0008	0.0012
RM-306	1.18110	0.0002	0.0006	2.83465	0	0.0008	1 3/16	0.020	0.020	0.080	0.080	0.0008	0.0012
RM-307	1.37795	0.0002	0.0006	3.14962	0	0.0008	1 3/8	0.020	0.020	0.080	0.080	0.0008	0.0012
RM-308	1.57481	0.0002	0.0006	3.54332	0	0.0008	1 7/16	0.020	0.020	0.080	0.080	0.0008	0.0012
RM-309	1.77166	0.0002	0.0006	3.93702	0	0.0008	1 9/16	0.020	0.020	0.080	0.080	0.0010	0.0016
RM-310	1.96851	0.0002	0.0006	4.33072	0	0.0008	1 3/4	0.020	0.020	0.080	0.080	0.0010	0.0016
RM-311	2.16536	0.0002	0.0006	4.72443	0	0.0008	1 15/16	0.020	0.020	0.080	0.080	0.0010	0.0016
RM-312	2.36221	0.0002	0.0006	5.11813	0	0.0008	2 1/8	0.020	0.020	0.080	0.080	0.0010	0.0016
RM-313	2.55906	0.0002	0.0006	5.51183	0	0.0008	2 5/16	0.020	0.020	0.120	0.120	0.0010	0.0016
RM-314	2.75591	0.0002	0.0007	5.90544	0	0.0012	2 1/2	0.020	0.020	0.120	0.120	0.0010	0.0016
RM-315	2.95277	0.0002	0.0007	6.29924	0	0.0012	2 11/16	0.020	0.020	0.120	0.120	0.0010	0.0016
RM-316	3.14962	0.0002	0.0007	6.69294	0	0.0012	2 11/16	0.020	0.020	0.120	0.120	0.0012	0.0018
RM-317	3.34647	0.0002	0.0007	7.08664	0	0.0012	2 7/8	0.020	0.020	0.120	0.120	0.0012	0.0018
RM-318	3.54332	0.0002	0.0007	7 48055	0	0.0012	2 7/8	0.020	0.020	0.120	0.120	0.0012	0.0018
RM-319	3.74017	0.0002	0.0007	7.87405	0	0.0012	3 1/16	0.020	0.020	0.120	0.120	0.0012	0.0018
RM-320	3.93702	0.0002	0.0007	8.46460	0	0.0012	3 1/4	0.020	0.020	0.120	0.120	0.0012	0.0018

straightedges at the point corresponding to their size. This particular machine is provided with eight compartments, and the variation between each compartment is 0.0001 inch. For gaging, the balls are placed in the hopper *A*, inside of which is an agitator operated by the belt *B*. This distributes the balls so that they come out of the spout *C* one at a time and drop into slide *D*. From this they are carried on by the agitator onto the straightedges *E* until they drop down into the required compartment.

Gaging and Inspecting Ball Bearing Race Rings. — The gaging of ball bearing races requires measurements of great refinement. The limits on the race rings are very close; for instance, on the hole in the inner race, which fits on the shaft, the limits are +0.0002, and −0.0004 inch. For the outside diameter of the outer race ring, the limits are +0.0004, and −0.0008 inch. In the ball bearing raceways, the variation is as great as 0.0003 inch. The limits on the hole of ball thrust bearing races are +0.0002 and −0.0004 inch. For the outside diameter, the limits are +0.0006 inch and −0.0012 inch. The limit for the height of single thrust bearings is +0.002 inch, and for the height of double-acting thrust bearings, +0.004 inch. Tables I, II, and III give tolerances for ball and roller bearings, respectively, as established by the Society of Automotive Engineers (S.A.E.). In the case of ball bearings, only the light series is listed; and in the case of roller bearings, only the narrow series is given. The tolerances, however, on the medium and heavy ball bearings and medium and wide roller bearings are the same.



Notation for Table III

For gaging ball bearings when machining, the micrometer caliper is extensively used for measuring all outside dimensions, and for internal measurements, plug gages or three-point indicating gages are generally adopted. The plug gage has been found unsatisfactory for gaging ball bearing race rings. The reason for this is that the operator does not know how much material remains to be removed, and, consequently, is working without any guidance until he reaches the "go" dimension on the gage. The result is that all grinding machine operators prefer to use some sort of indicating gage which gives them some latitude. One ball bearing manufacturer has

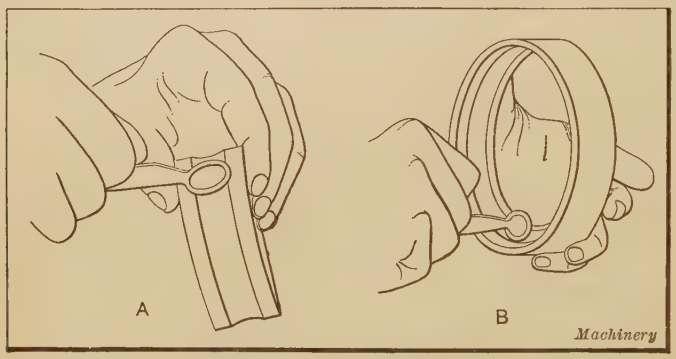


Fig. 59. Use of Templet for Inspecting Raceways in Outer and Inner Ball Bearing Rings

devised a three-point indicating gage for use on the grinding machine for internal work which is used entirely by the machine operators and has been found to give satisfactory results.

For external grinding, snap gages are seldom used. Attempts have been made by one manufacturer to replace the micrometer caliper with a dial test indicating gage. This proved unsatisfactory, however, owing to the excessive fluctuations to which the needle is subjected when it is necessary to slide the gaging point over the work. On a dial test indicator which is made to read to 0.0001 inch, very little irregularity in the surface of the work causes a considerable movement of the needle, and as there is no "damping," or effective means of preventing oscillations of the needle, it is difficult to use this type of gage

for snap work. Consequently, it is the rule in practically all plants making ball bearing race rings to use micrometer calipers in the manufacturing departments. The inspectors are furnished with plug and snap gages of the limit type.

Plug gages for ball bearing races must be made light, so as not to fatigue the inspector. With a plug gage, say 3 inches in diameter, made from solid tool steel, the weight is objectionable, and several manufacturers reduce the weight of large plug gages by making the gaging part in the form of a ring which is held on an aluminum core. The aluminum core is extended to form the handle and is knurled as usual. In some plants, plug gages that have become worn are annealed and turned down to the next size. They are then hardened, ground and lapped, and in this way can be used a great many times.

Gaging Raceways in Annular Ball Bearing Rings. — The raceways or grooves in ball bearing rings must be carefully checked. The shape of the curve is usually checked by templet gages, as illustrated at *A* and *B* in Fig. 59. For testing the diameter of the raceway in the inner and outer rings, various means are employed, the most common being that in which three balls are used to determine the correct depth. Another method makes use of a micrometer caliper having three ball points.

Gaging Raceways in Thrust Bearings. — For thrust bearing race rings, it is necessary that the raceway be concentric with the bore of the ring; also that it be of the correct depth and of the proper radius. A satisfactory indicating gage for testing race rings is shown in Fig. 60; the race ring being tested is that used on the main drive shaft of an automobile. The gage rests on a cast-iron stand *A* in which a hardened and ground steel ring *B* is held. The top part of this ring is made a good fit for the inside diameter of the ball bearing race ring *C*. A stud *D*, held to the base by a nut as shown, is slotted to receive the gage plate *E*. Stud *D* is hardened and ground and plate *E* has a reinforcing plate *F* held to it by rivets, the latter being hardened and ground and made a good fit in the slot in the stud. The fulcrum of the pointer or needle *G* is so placed that

any variation in the work is magnified twenty-five times at the point where the reading is taken. A knurled handle *H* is fastened to the gage for convenience in holding the gage.

The work is slipped over the ring *B* of the gage, as shown; then the gage plate *E* is placed in the slot in stud *D*, and the gaging knife-edge rollers *I*, which in this case do not rotate but are held rigidly to the frame, are placed in the ball race groove. The position of the indicating point of the needle is then noted to see if the race is of the required diameter. A

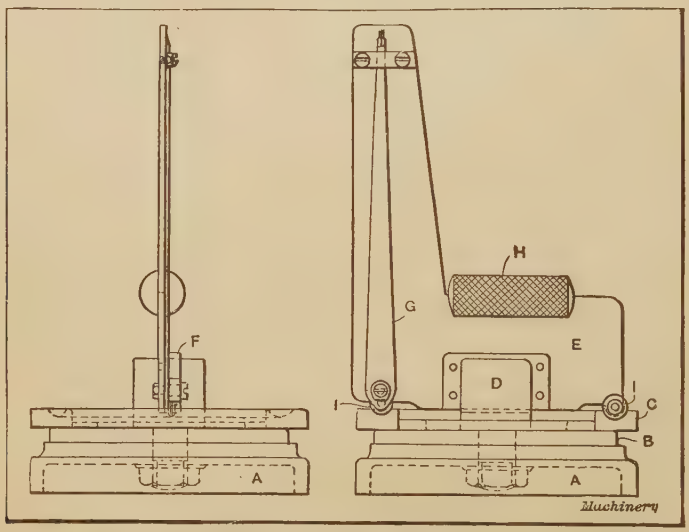


Fig. 60. Special Indicating Device for Testing Raceways in Thrust Bearing Race Rings

limit of 0.001 inch is allowed on the diameter of the ball race groove. The base of this gage is fastened to a frame, not shown, which is of sufficient height to bring the ring to be gaged in line with the operator's vision.

Testing Diameters of Inner and Outer Race Rings. — As has been previously mentioned, the outer diameters of the inner and outer race rings are generally inspected by snap gages or indicating gages. Fig. 61 shows the Hirth minimeter being used for this work; the graduated scale on this minimeter is such as to give readings to 0.0001 inch, and it has been found

very satisfactory for work of such refinement. For gaging the interior or hole in the outer and inner races, plug gages are

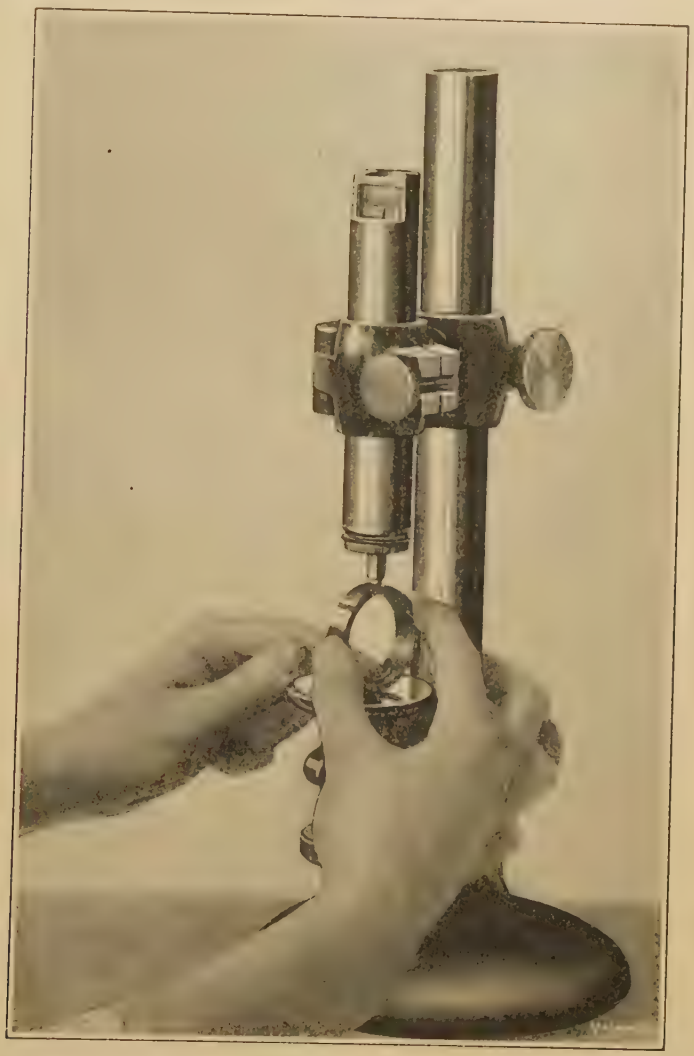


Fig. 61. Hirth Minimeter set up and in Use for Testing External Diameter of Ball Bearing Race Rings

sometimes used, but a more satisfactory gage is shown in Fig. 20. This shows a Hirth minimeter with a special attachment

by means of which it is possible to tell whether the diameter is correct or not, and whether the hole is out of round, tapered, etc.

Testing Concentricity of Ball Bearings. — In order to determine if the ball bearing will run true within the required limits, the cone or center race is tested for wobble or concentricity.

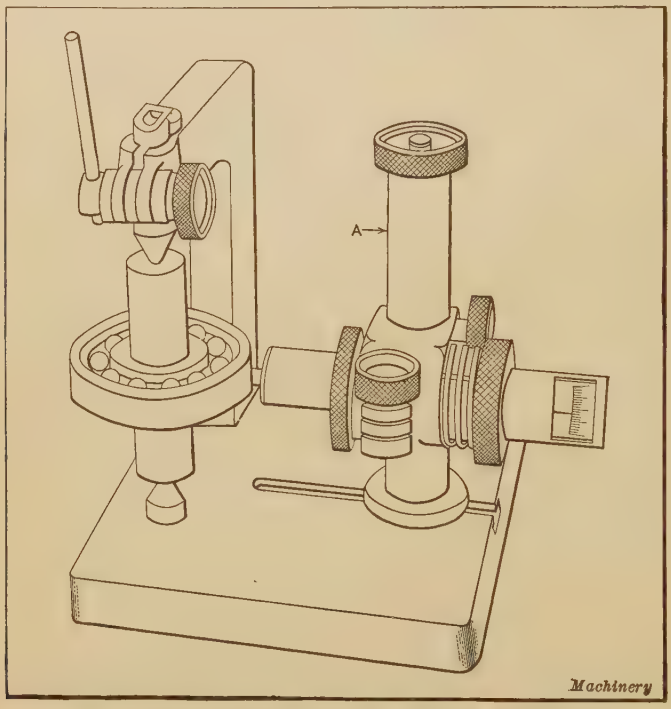


Fig. 62. Special Inspecting Fixture for Testing Side Wobble and Concentricity of Assembled Ball Bearings

Usually this is done by supporting the inner ring or cone on an arbor and using an indicating gage similar to that illustrated in Fig. 62, where a completed ball bearing is shown being tested. In testing a ball bearing for concentricity after the balls, retainers, and inner and outer races have been assembled, the inner race is forced by hand carefully onto a hardened and ground arbor. This arbor is then placed between centers, as shown in Fig. 62, and the carrier *A* holding a Hirth minimeter

is brought up so that the needle stands at zero when it is brought in contact with the outer race. The outer ring is then rotated independently of the inner one, also on centers, and the amount of side wobble or eccentricity is noted on the minimeter scale.

The amount of wobble allowed in a ball bearing depends upon its size; it is usually not greater than 0.001 or 0.002 inch for large bearings, and is less than this for smaller sizes. The axial wobble or thrust, that is, the displacement of the inner race with respect to the outer, is not of so great importance as the radial wobble. Experiments in various shops have

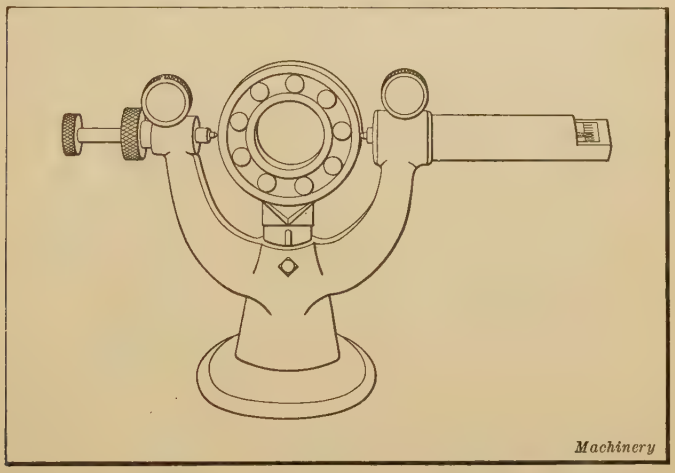


Fig. 63. Special Type of Three-point Gage using Hirth Minimeter for Testing Roundness and Diameter of Assembled Ball Bearing

shown that a slight axial clearance does not appreciably affect the durability of the ball bearing. In general, a clearance of 0.002 or 0.003 inch may be regarded as advantageous.

Testing External Diameter of Completed Ball Bearings. — A simple but satisfactory means of gaging the external diameter of a completely assembled ball bearing is shown in Fig. 63. This gage is built in the form of a snap gage and has in the middle a movable V-support, which is set in accordance with the diameter of the bearing being measured. One of the two measuring points has a coarse adjustment by means of an adjusting screw, which fits in holes 0.040 inch apart, and a

fine adjustment by means of a micrometer. The measurement is taken with a Hirth minimeter, which is brought in contact with the opposite side of the ball bearing. The bearing is rotated while being tested, so that its roundness can be tested at the same time as the diameter. This particular gage is set by means of a master ring.

Box Type Inspection Fixtures. — The gaging of single holes, shafts, and similar work is a comparatively simple proposition as compared with the gaging of parts having a multiplicity of holes that must bear some definite relation to each other and to finished surfaces. Formerly many manufacturers depended upon their jigs and fixtures to obtain the desired amount of accuracy. Jigs and fixtures, however, cannot be depended upon to remain accurate for any considerable length of time, especially when they are roughly handled, and if the work that comes from these fixtures must be accurate, it is highly desirable that the fixtures be tested frequently. Another point which must be considered is the fact that a box type of jig is likely to drill and ream work inaccurately if not kept clean by the operator. The collection of dirt in one corner of a box jig would easily throw the work out to such an extent that holes which are to bear a certain relation to a milled surface would be located inaccurately. Consequently, the most desirable practice is to gage the work after it comes from the jig. The importance of this will be more fully appreciated when it is remembered that most drilling machine work is done by inexperienced mechanics — men who know little about accurate work, and simply have sufficient knowledge to put the work in the jig, take it out again, and operate the machine. The Dayton Engineering Laboratories Co. has developed an interesting system of box gaging which is used to a large extent throughout the various manufacturing departments in its plant. This type of gage has been developed primarily in an endeavor to produce electric starting, ignition and lighting equipments on a truly interchangeable basis. In the following are described some of the gages used in this plant which incorporate interesting features.

Gaging Milled Surfaces in Relation to Dowel-pin Holes. — Fig. 64 shows an interesting box gaging fixture which is used to determine the location of a reamed hole and milled surface on a generator end-frame in relation to the dowel-pin holes. The fixture is provided with hardened and ground dowel-pins *A* which fit in the dowel-pin holes of the work, and a hardened and ground plug *B* operated by plug *C*. When the work *D* is placed on the dowel-pins, plug *B* is raised into the hole, and if the hole is correct, the plug will pass through; if not, the

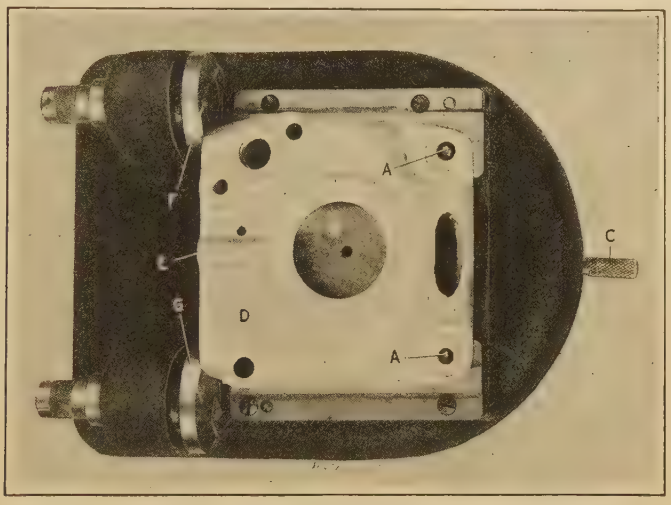


Fig. 64. Special Type of Box Gaging Fixture used for Inspecting Relation of Bore to Milled Surfaces on an Electric Starter Generator Frame

plug will not rise. The limits on the work are provided for by having the plug the required amount smaller than the hole in the work. The milled surface on the work is inspected by means of the rotating plug gages *F* and *G*. These are each provided with two bosses, one of which is made to indicate the "go" and the other the "not go" dimension. These projections are then swung past the milled surface on the work, and if the "go" end passes by and the "not go" does not, the work is within the required limits. In this case, the toler-

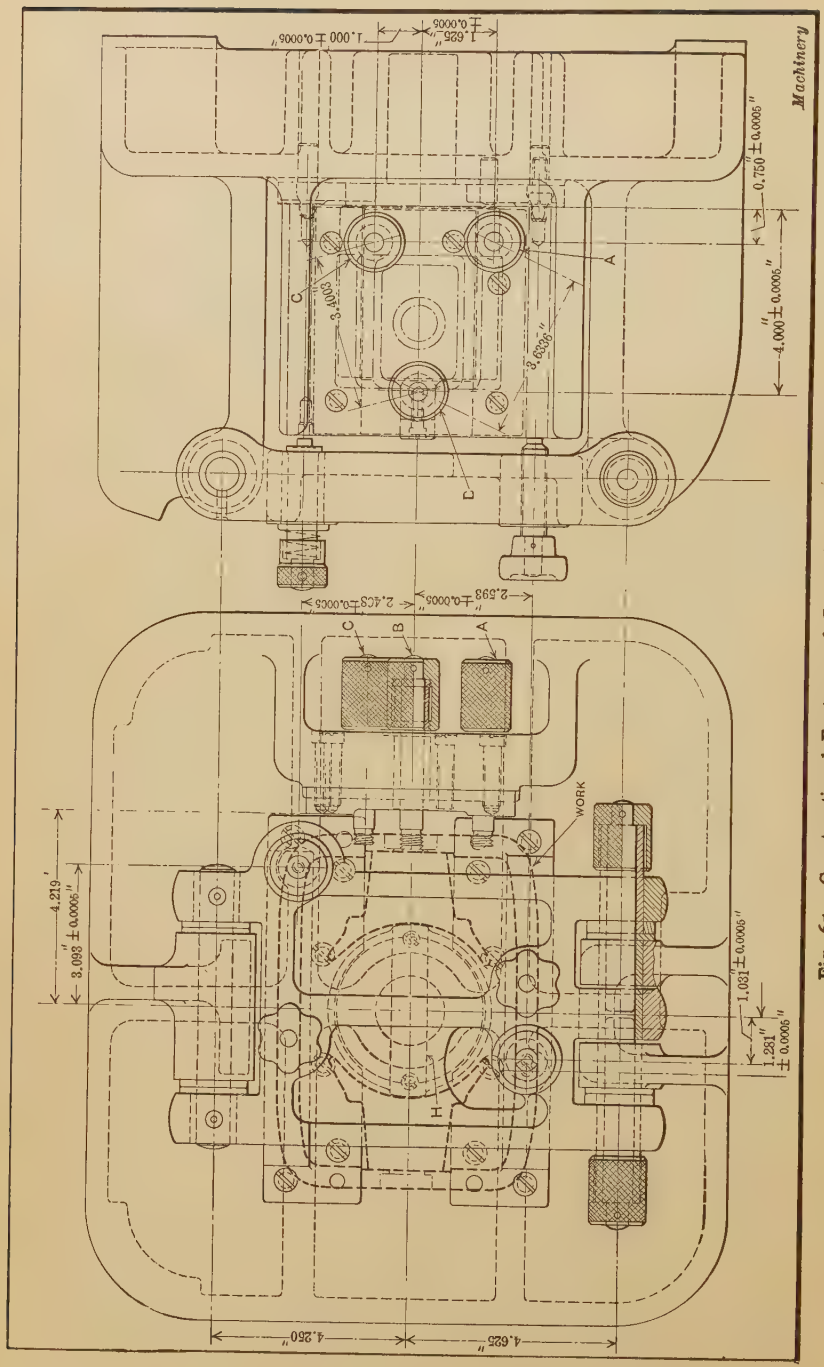


Fig. 65. Constructional Features of Gage shown in Fig. 66

ance allowed on the milled surface is 0.002 inch, and on the hole the limits are ±0.001 inch.

Box Inspection Gage for Generator Frame. — An interesting and practical application of the box type of gaging fixture is shown in Figs. 65 and 66. This gaging fixture is used for inspecting the location of the various holes in the generator frame, and is constructed along the same lines as the drilling jig used in producing the holes. The points to be gaged are three threaded holes which must bear a definite relation to the

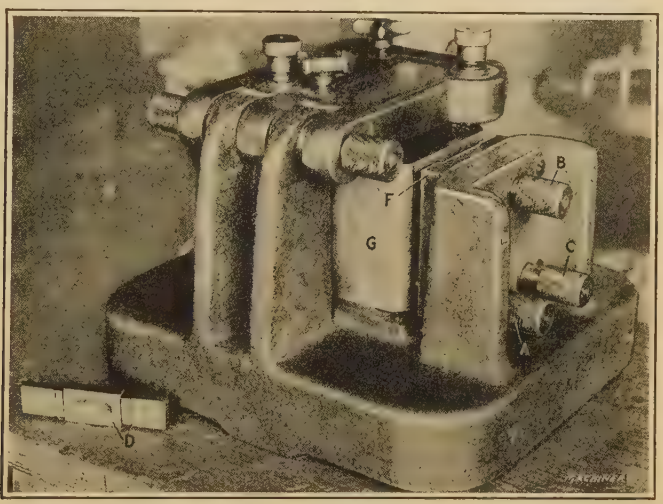


Fig. 66. Box Type of Gage for Inspecting Tapped Holes and Milled Surfaces on Electric Starter Generator Frame

milled surface, and, in addition, the milled surface must bear a certain relation to the center hole. The three holes are gaged, respectively, by the plugs *A*, *B*, and *C*. The location of the milled surface is inspected by the limit gage *D*, Fig. 66, which is of the feeler type and is inserted between the hardened and ground plate *F* and the work *G*. Reference to Fig. 65 will show the variation allowed in the fixture in the location of the three tapped holes, which is ±0.0005 inch. The limits on the work are still wider and are controlled by means of the variation between the pitch diameter of the plug gage and the

threaded hole in the work. The location of the milled surface on the work in relation to the central hole also has limits of ±0.0005 inch in the manufacture of the gage, whereas the work has a tolerance of 0.002 inch. The bore is inspected by swinging end-measuring bar *H*, Fig. 65, which is fulcrumed on a central stud and has "go" and "not go" ends.

Fig. 67. Another Type of Generator Frame Inspection Fixture

Reference to Fig. 66 will show that this gage is constructed of cast iron, but all wearing surfaces are made of tool steel or machine steel, casehardened and ground. It consists primarily of a base on which a measuring surface is screwed and a swinging plate fulcrumed at the rear of the fixture and held

down by means of two hardened and ground plugs. The swinging plate is provided with two clamping screws in the center and two spring plungers. The clamping screws are brought down lightly and the springs are depended upon to keep the work tightly against the lower surface of the fixture.

Fig. 67 shows another generator frame gaging fixture which is constructed on the same principle as that illustrated in Figs. 65 and 66. In this case, the generator is of different shape, and the fixture is shown with the lid up, exposing its interior construction. Reference to this illustration will show that the pole-piece bearings are inspected by means of a swinging gage *A* having "go" and "not go" ends. The bar is grasped by the inspector and is swung around past the poles to determine if they are of the correct diameter. The lid is then swung down and the feeler gage *B* used to determine if the frame is of the required length in relation to the central hole or axis. On the opposite end is a hole which must be gaged; this is done by a plug gage which is smaller than the hole in the work by an amount equal to the limits allowed.

Two additional gaging fixtures are shown in Fig. 68. The one to the left is built along similar lines to the generator frame gage shown in Fig. 65. This gage shows the work removed and illustrates the method of locating and gaging it. The work fits over the stud *O*, and is provided with a slot in which plunger *A* fits. A feeler gage is then inserted between the hardened plate *B* and the work to inspect the position of this slot, as well as of the milled surface in relation to the central hole. There is a bushed hole *C* in the top cover plate through which a plug is inserted for gaging a corresponding hole in the work. The fixture is provided with gaging seats in which dowel-pins are located for centering the work. The hinge plate is bushed, and is located accurately by hardened, ground and lapped plugs.

Another inspection fixture is illustrated to the right in Fig. 68. This gage is also used for inspecting a generator frame, and determines the relation of a second bored hole having two diameters at right angles to the first which is located from

stud *F*. The work is located by two dowel-pins, and the central plug is raised by operating lever *G*. The non-rotating traverse plugs *D* and *E* and the central one determine the relation of the center distances between the spiral gears in the generator frame, and the relation of these holes may vary more in one direction than in another. In addition, two other rotating "go" and "not go" plugs *H* and *I* are used to deter-

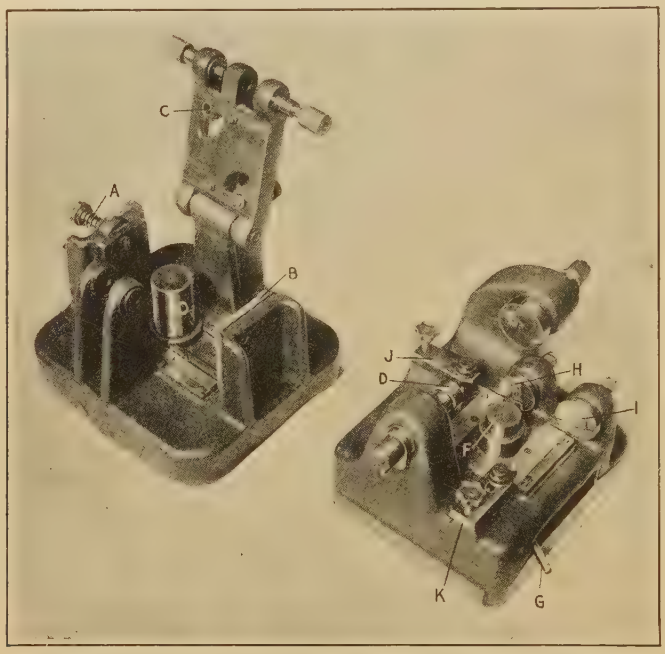


Fig. 68. Two Generator Inspection Fixtures somewhat Different from those previously illustrated

mine the location of the milled surface. The work is held in place by toe-clamps *J* and *K*. The same locating and clamping points are used in the gaging fixture as were used in machining the parts. These gages cover principles having a wide application in general manufacturing work. They determine accurately the relations of the milled surfaces to the machined holes within limits that are close for work of this kind.

Gaging Watch Escapements. — The detached lever escapement is considered by horologists to be one of the most difficult parts of a watch movement to manufacture, because of the important function it fills in the proper timing of a watch. It transforms the rotary motion of the train of wheels into the vibratory movement of the balance, and at the same time acts as a brake to prevent the watch mechanism from "running away," retarding the motion of the wheels, and imparting the correct movement to the hands on the dial. To design an escapement properly requires not only considerable experience in this work, but also a clear understanding of the functions that this important part of a watch has to fill. The first step in producing a watch escapement is to lay it out on paper on an enlarged scale of 50 to 1, and then, by means of certain parts outlined on tracing cloth, to study the movements in the manner that they take place in the watch. The proper manufacture of an escapement does not end here, and, in fact, the most difficult work — producing the various parts correctly — is still to follow. Several methods have been adopted in different watch-making plants to check up the machining operations, in order to determine whether or not they have been properly executed.

Projector Methods for Testing Watch Escapements. — One method which is used to a considerable extent is to employ a projector (an instrument designed on the principle of the magic lantern) to project and enlarge the escapement in order to determine if the machining operations have been correctly done. The escapement to be projected is placed on a pane of glass set in the frame of the projector where it is held flat against the surface of the glass by a spring. The projector is then placed in a dark room in such a relation to a screen as to obtain an enlargement of the escapement of ten diameters. The screen used generally consists of a sheet of drawing paper and the outline of the projected escapement is traced with a pencil. This sheet is then removed and the various functions, angles, etc., of the escapement are measured on this enlarged scale. The drawing paper may be replaced by a

photographic plate and a photograph taken, but this process requires considerable time and is seldom used.

Microscope with Illuminated Chamber. — Another method consists of a microscope with an illuminated chamber, mounted in such a manner as to give an enlargement of ten diameters and provided with a prism and a mirror, enabling the object to be set outside the microscope in order that its projection may be traced. The microscope is furnished with a screw, the barrel of which is provided with 100 divisions and enables measurements to be obtained to one thousandth millimeter. The lever escapement thus enlarged ten times with the aid of the microscope is then analyzed. The calibrated screw is used to check up the dimensions.

Method of Gaging Escapements employed by the South Bend Watch Co. — A third method is that used by the South Bend Watch Co., South Bend, Ind. This method consists in using gages which are very accurately made for measuring the various functions and members of a watch escapement. While the two methods previously described would seem to be scientific in their exactness, there is always a question in the mind of the mechanic as to the practicability of this procedure in work of an interchangeable character. There is little, if anything, to be gained by using methods of measurement which are much more accurate and worked down to greater degree of refinement than it is possible to obtain when manufacturing the parts on a commercial basis. For instance, by means of the microscope and illuminating chamber, it is possible to obtain dimensions to within one thousandth millimeter. It is practically impossible to duplicate this accuracy on thousands of parts produced with cutters in a mechanically-operated machine. One piece could probably be made, but the slightest wear on the cutters would mean that this refinement would be lost. Gages can be made of sufficient accuracy to check any variations in the work that may occur due to the wear of cutters or improper setting. Furthermore, the gages are at all times at hand to test the parts and determine just how soon a slight error has crept in. If gages were not fur-

nished it would be necessary to test the parts at short intervals as previously described, which would not only be impracticable, but would not fill the requirements of the case.

In order to make the following description of the gages clear, reference should be made to Fig. 69 in which the various

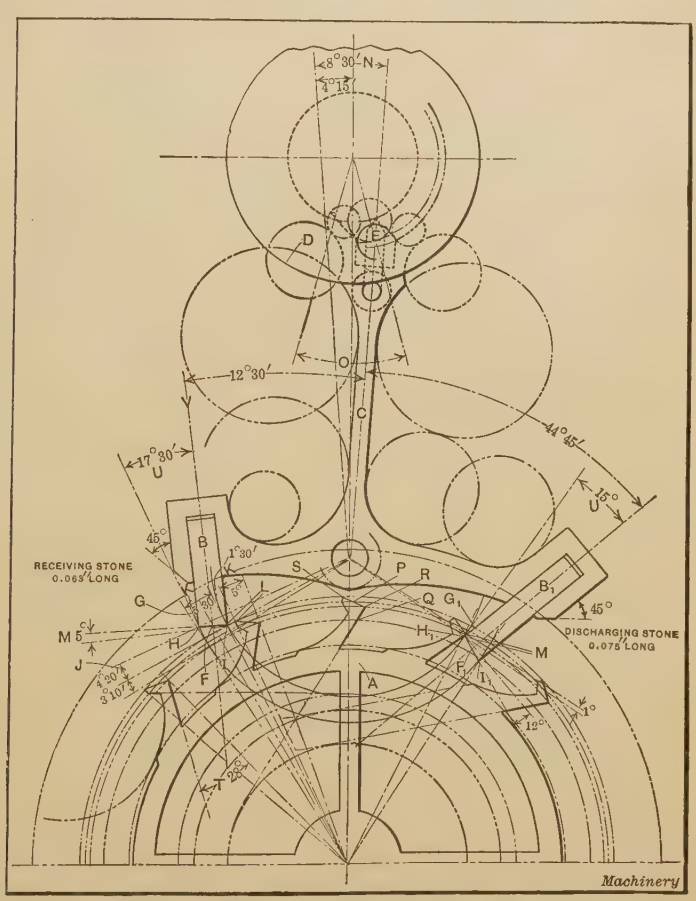


Fig. 69. Diagram illustrating Method of analyzing a Detached Lever Watch Escapement

members of a detached lever escapement that require consideration are clearly outlined. These various members are indicated by letters, the functions and names of which are as follows: A, escape-wheel; B, receiving pallet stone; B_1,

discharging pallet stone; *C*, fork; *D*, roller; *E*, impulse pin; *F*, impulse face of receiving stone; F_1, impulse face of discharging stone; *G*, locking face of receiving stone; G_1, locking face of discharging stone; *H*, locking corner of receiving stone; H_1, locking corner of discharging stone; *I*, releasing corner of receiving stone; I_1, releasing corner of discharging stone; *J*, lift of pallet; *K*, circular impulse; *L*, drop; *M*, lock; *N*, arc of impulse fork; *O*, arc of impulse of roller; *P*, impulse face of escape-wheel tooth; *Q*, locking face of escape-wheel tooth; *R*, locking corner of escape-wheel tooth; *S*, releasing corner of escape-wheel tooth; *T*, locking angle of escape-wheel tooth; and *U*, draft angle of pallet stone.

Fig. 70. Gage for Measuring Different Angles on the Escape-wheel Teeth

Each one of the functions of the detached lever escapement must be checked after machining in order to determine if the requirements secured by graphic methods and mathematical calculations have been obtained. The first gage which is used is shown in Fig. 70; the object of this is to measure the different angles on the escape-wheel teeth. It measures the angle that the impulse face *P* of the escape-wheel tooth makes with a tangent to the periphery of the escape-wheel at the releasing corner *S*; it measures the angle that the locking face *Q* of the escape-wheel tooth makes with a radial line drawn from the

center of the wheel to the locking corner R, and it also measures the periphery diameter of the escape-wheel teeth. Straightedges B and C are used to measure the angles of the escape-wheel teeth and are set by plugs placed in the centers of the recesses, the radii of these plugs being the sines of the angles to be measured. When it is stated that 0.0001 inch of variation can be clearly indicated on a gage provided with knife-

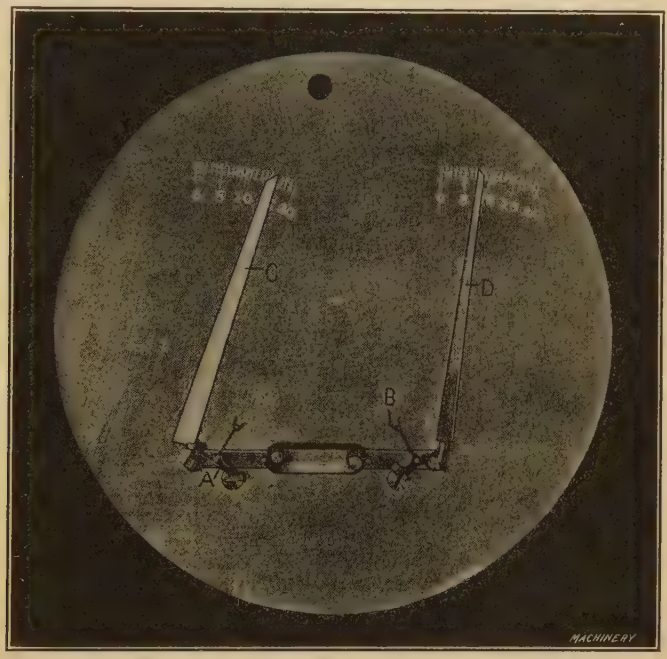


Fig. 71. Gage for Measuring Position of the Forks, Pallet Stones, Etc., of Detached Lever Escapement

edge straightedges similar to that furnished on this gage, it will be evident that this method of gaging is practically as exact a method as it is possible to obtain; at least, it is accurate enough to detect any errors in machining which would affect the efficient working of the escapement.

The circular gage shown in Fig. 71, in which two forks A and B are located on pins, is used with the aid of straightedges C and D to measure the draft angle U of the pallet stone, and also

the angle that the impulse face of the stone makes with a line V passing through its center. (See Fig. 69.) This gage also measures the distance from the center of the pallet to the locking corners H and H_1 and the releasing corners I and I_1 of the pallet stones. In this particular case, the draft angle of the receiving stone measures $15\frac{3}{4}$ degrees, and the draft angle of the discharging stone, $7\frac{1}{4}$ degrees.

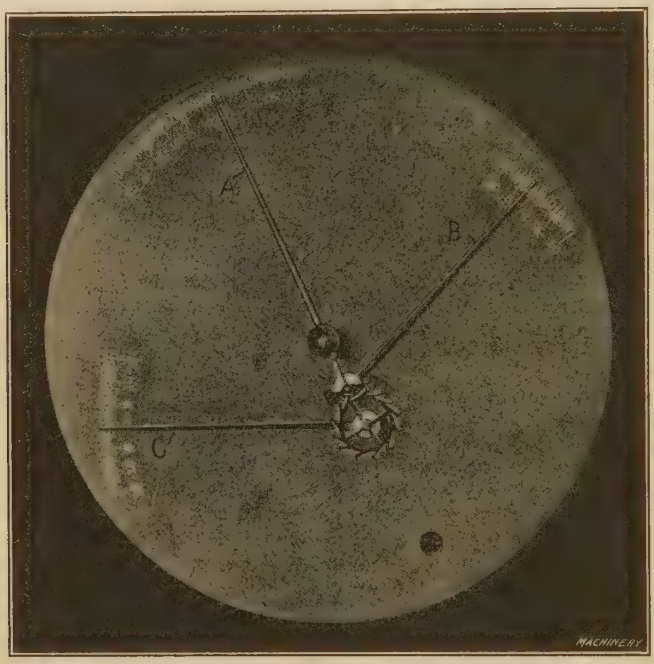


Fig. 72. Gage for Measuring a Complete Assembled Escapement

The third circular gage shown in Fig. 72, upon which the completed escapement is held, is used for the following measurements: Impulse face F and F_1 of pallet stones; the drop L; the lock M; the arc of impulse N of the fork; the arc of impulse O of the roller; the recoil of the escape-wheel in unlocking the slide or run of the escape-wheel; and the side shake of the impulse pin in the fork slot. These circular impulses of both wheel teeth and stones are taken as angular measurements from the center of the escape-wheel. The positions of the

needles A, B, and C have a meaning only when compared with their positions before the action of the escapement took place. The office of these needles, therefore, is to measure the angular distance at the beginning and at the end of each action.

By the use of these three gages, all the functions of the detached lever escapement that it is desirable to know may be measured. An escapement can be taken from a watch and measured at every particular point. Furthermore, these gages are not made until an escapement has been produced which works as efficiently as it is possible to make it; then the various parts of the escapement are removed and the gages made to them, ideal conditions being realized in this way. It is also possible, by the use of these gages, to construct a perfect working escapement from a very much enlarged drawing with the positive assurance that it will be an exact miniature. This latter method, from a mechanical standpoint, would appear to be much more practical and exact than those previously described.

CHAPTER VI

GAGING AND INSPECTING SCREW THREADS

The production of screw threads on an interchangeable basis is one of the most difficult problems encountered in applying the limit system. Considerable difference of opinion exists in regard to the question of manufacturing tolerances on the various elements of a screw thread, and in the following, this point, as well as several others of importance, will be reviewed.

Elements of Screw Threads. — The elements of a screw thread are indicated in Fig. 1, and in the following paragraphs are given the names used to define elements of screw threads:

A is the *pitch diameter* of a screw and is the distance between the pitch lines, which are located where the width of the thread and the space are the same and equal to one-half the pitch. This element is also known as the *angle diameter* or the *effective diameter*.

B is the *outside diameter* of a screw and is measured at right angles to the axis. This element is also known as the *full diameter* or the *external diameter*.

C is the smallest diameter of a screw thread and is measured at right angles to the axis. This element is known as the *root diameter* or the *core diameter*.

D is the *pitch* and is the distance between the centers of any two adjacent threads, measured parallel with the axis of the screw.

E is the *included angle* of the thread, measured in an axial plane.

F is the *slope* of a thread.

G is the *crest* of the thread in the screw or nut, respectively. This part is also known as the *top* and the *flat* on the U. S. standard form of threads.

H is the *root* of the thread in the screw or nut, respectively. This element is also known as the *bottom* of the thread.

The *lead* of the screw is the distance that the screw travels in a longitudinal direction when given one complete turn in a nut.

In the case of the standard V-thread, shown at *A* in Fig. 2, there are five points to be measured in both the screw and the nut. An error in any one of these points will, theoretically, prevent the screw and nut from fitting together properly. In the Cadillac form of thread, shown at *B*, two of these points are eliminated, leaving only the pitch diameter, pitch, and angle of thread to be considered on the screw and the nut.

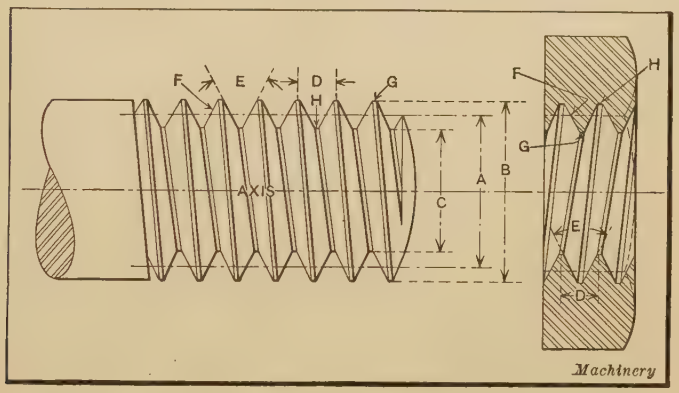


Fig. 1. Diagram illustrating Various Elements of a Screw Thread

Theoretically, the shape of the threads shown at *C*, *D*, and *E* in Fig. 2 present five elements that must be correct before the screw and nut will fit together properly. The Acme thread, shown at *F*, has a clearance at the top and bottom, leaving only three out of the five elements to be considered. In actual practice, the U. S. standard form of thread is made with a clearance at the top and bottom, and the chief points are to have the thread correct on the angular faces, and the pitch and the pitch diameter correct. Tolerances, however, have never been generally accepted, and it is for this reason that so much uncertainty exists as to tolerances that should be given on threaded parts for various classes of work.

Tolerances on Screw Threads. — The three points that receive the most careful attention in the production of a screw thread are the pitch, the pitch diameter, and the angle of the thread. In the U. S. standard thread, errors in pitch may be compensated for by reducing the pitch diameter by an amount

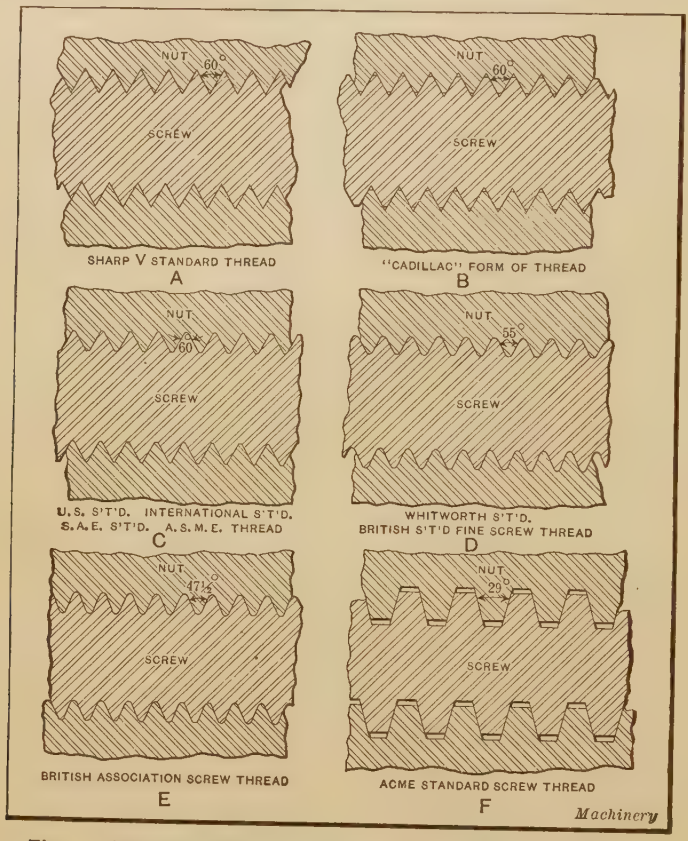


Fig. 2. Diagrams illustrating Various Forms of Screw Threads

equal to about three times the pitch error. In threaded parts that must fit well together, however, this method of obtaining a fit is not recommended. The permissible error in pitch or lead is dependent upon the length of the thread in the nut. The longer the nut, the smaller will be the amount of error permissible in the lead. Another factor that must be considered

in fitting a screw and a nut is the angle of the thread. This element can be compensated for by a reduction or increase of the pitch diameter.

The Engineering Standards Committee of Great Britain has given the subject of screw-thread tolerances considerable attention, and has established certain tolerances for different classes of fits. The formulas established for determining the tolerances and allowances on the outside and root diameters of the bolt and nut for the British standard Whitworth and the British standard fine screw threads are given in the following, and the data for the British standard Whitworth thread are also given in Tables I and II. The tolerances and allowances on the British standard Whitworth thread are found by the following formulas:

$$\text{Tolerance on outside diameter of bolt} = -0.0035 \times \sqrt{D}\ \text{inch}, \quad (1)$$

$$\text{Tolerance on root diameter of bolt} = -0.0045 \times \sqrt{D}\ \text{inch}, \quad (2)$$

$$\text{Tolerance between bolt and nut} = +0.001 \times \sqrt{D}\ \text{inch}, \quad (3)$$

$$\text{Tolerance on outside and root diameters of nut} = +0.0035 \times \sqrt{D}\ \text{inch}, \quad (4)$$

in which D = nominal diameter of the thread in inches.

The positive and negative signs refer to the direction in which the tolerance is permitted on the bolt and the nut, respectively. The tolerance on the outside and root diameters of the nut established by Formula (4) is to be added to the allowance given by Formula (3).

The formulas used for determining the tolerances and allowances on British standard fine threads are as follows:

$$\text{Tolerance on outside diameter of bolt} = -0.0025 \times \sqrt{D}\ \text{inch}, \quad (5)$$

$$\text{Tolerance on root diameter of bolt} = -0.0035 \times \sqrt{D}\ \text{inch}, \quad (6)$$

$$\text{Allowance of nut} = +0.001 \times \sqrt{D}\ \text{inch}, \quad (7)$$

$$\text{Tolerance on outside and root diameters of nut} = +0.0025 \times \sqrt{D}\ \text{inch}. \quad (8)$$

The amount established by Formula (8) is to be added to that obtained by Formula (7).

Table I. British Standard Whitworth Screw Threads — Tolerances for Bolts

Nominal Diameter of Screw, Inches	Number of Threads per Inch	Tolerance on Pitch per Inch Length of Thread, Inch	Outside Diameter, Inches			Pitch Diameter, Inches			Root Diameter, Inches		
			Maximum	Minimum	Tolerance	Maximum for a Screw of Correct Pitch*	Minimum	Tolerance	Maximum	Minimum	Tolerance
1/4	20.0	0.0035	0.2500	0.2482	0.0018	0.2180	0.2162	0.0018	0.1860	0.1837	0.0023
5/16	18.0	0.0033	0.3125	0.3105	0.0020	0.2769	0.2748	0.0021	0.2414	0.2389	0.0025
3/8	16.0	0.0032	0.3750	0.3729	0.0021	0.3350	0.3326	0.0024	0.2950	0.2922	0.0028
7/16	14.0	0.0031	0.4375	0.4352	0.0023	0.3918	0.3891	0.0027	0.3460	0.3430	0.0030
1/2	12.0	0.0030	0.5000	0.4975	0.0025	0.4466	0.4436	0.0030	0.3933	0.3901	0.0032
9/16	12.0	0.0029	0.5625	0.5599	0.0026	0.5091	0.5059	0.0032	0.4558	0.4524	0.0034
5/8	11.0	0.0028	0.6250	0.6222	0.0028	0.5668	0.5633	0.0035	0.5086	0.5050	0.0036
11/16	11.0	0.0027	0.6875	0.6846	0.0029	0.6293	0.6255	0.0038	0.5711	0.5674	0.0037
3/4	10.0	0.0027	0.7500	0.7470	0.0030	0.6860	0.6820	0.0040	0.6219	0.6180	0.0039
13/16	10.0	0.0026	0.8125	0.8093	0.0032	0.7485	0.7442	0.0043	0.6844	0.6803	0.0041
7/8	9.0	0.0026	0.8750	0.8717	0.0033	0.8039	0.7994	0.0045	0.7327	0.7285	0.0042
15/16	9.0	0.0025	0.9375	0.9341	0.0034	0.8664	0.8616	0.0048	0.7952	0.7908	0.0044
1	8.0	0.0025	1.0000	0.9965	0.0035	0.9200	0.9150	0.0050	0.8399	0.8354	0.0045
1 1/8	7.0	0.0024	1.1250	1.1213	0.0037	1.0335	1.0280	0.0055	0.9420	0.9372	0.0048
1 1/4	7.0	0.0024	1.2500	1.2461	0.0039	1.1585	1.1526	0.0059	1.0670	1.0620	0.0050
1 3/8	6.0	0.0023	1.3750	1.3709	0.0041	1.2683	1.2620	0.0063	1.1616	1.1563	0.0053
1 1/2	6.0	0.0023	1.5000	1.4957	0.0043	1.3933	1.3865	0.0068	1.2866	1.2811	0.0055
1 5/8	5.0	0.0022	1.6250	1.6205	0.0045	1.4969	1.4897	0.0072	1.3689	1.3632	0.0057
1 3/4	5.0	0.0022	1.7500	1.7454	0.0046	1.6219	1.6143	0.0076	1.4939	1.4879	0.0060
1 7/8	4.5	0.0021	1.8750	1.8702	0.0048	1.7327	1.7247	0.0080	1.5904	1.5842	0.0062
2	4.5	0.0021	2.0000	1.9950	0.0050	1.8577	1.8493	0.0084	1.7154	1.7090	0.0064
2 1/8	4.5	0.0021	2.1250	2.1199	0.0051	1.9827	1.9739	0.0088	1.8404	1.8338	0.0066
2 1/4	4.0	0.0020	2.2500	2.2447	0.0053	2.0899	2.0807	0.0092	1.9298	1.9230	0.0068
2 3/8	4.0	0.0020	2.3750	2.3696	0.0054	2.2149	2.2053	0.0096	2.0548	2.0479	0.0069
2 1/2	4.0	0.0020	2.5000	2.4945	0.0055	2.3399	2.3300	0.0099	2.1798	2.1727	0.0071
2 5/8	4.0	0.0020	2.6250	2.6193	0.0057	2.4649	2.4546	0.0103	2.3048	2.2975	0.0073
2 3/4	3.5	0.0019	2.7500	2.7442	0.0058	2.5670	2.5563	0.0107	2.3841	2.3766	0.0075
2 7/8	3.5	0.0019	2.8750	2.8691	0.0059	2.6920	2.6810	0.0110	2.5091	2.5015	0.0076
3	3.5	0.0019	3.0000	2.9940	0.0060	2.8170	2.8056	0.0114	2.6341	2.6263	0.0078

* The maximum pitch diameter is decreased when the screw is incorrect in pitch by the amount compensating for such error given in Table III.

Table II. British Standard Whitworth Screw Threads — Tolerances for Nuts

Nominal Diameter of Screw, Inches	Number of Threads per Inch	Tolerance on Pitch per Inch Length of Thread, Inch	Outside Diameter, Inches			Pitch Diameter, Inches			Root Diameter, Inches		
			Maximum	Minimum	Tolerance	Maximum	Minimum for a Nut of Correct Pitch*	Tolerance	Maximum	Minimum	Tolerance
1/4	20.0	0.0035	0.2523	0.2505	0.0018	0.2203	0.2185	0.0018	0.1883	0.1865	0.0018
5/16	18.0	0.0033	0.3151	0.3131	0.0020	0.2796	0.2775	0.0021	0.2440	0.2420	0.0020
3/8	16.0	0.0032	0.3777	0.3756	0.0021	0.3380	0.3356	0.0024	0.2977	0.2956	0.0021
7/16	14.0	0.0031	0.4405	0.4382	0.0023	0.3952	0.3925	0.0027	0.3490	0.3467	0.0023
1/2	12.0	0.0030	0.5032	0.5007	0.0025	0.4503	0.4473	0.0030	0.3965	0.3940	0.0025
9/16	12.0	0.0029	0.5659	0.5633	0.0026	0.5131	0.5099	0.0032	0.4592	0.4566	0.0026
5/8	11.0	0.0028	0.6286	0.6258	0.0028	0.5711	0.5676	0.0035	0.5122	0.5094	0.0028
11/16	11.0	0.0027	0.6912	0.6883	0.0029	0.6339	0.6301	0.0038	0.5748	0.5719	0.0029
3/4	10.0	0.0027	0.7539	0.7509	0.0030	0.6909	0.6869	0.0040	0.6258	0.6228	0.0030
13/16	10.0	0.0026	0.8166	0.8134	0.0032	0.7537	0.7494	0.0043	0.6885	0.6853	0.0032
7/8	9.0	0.0026	0.8792	0.8759	0.0033	0.8093	0.8048	0.0045	0.7369	0.7336	0.0033
15/16	9.0	0.0025	0.9419	0.9385	0.0034	0.8722	0.8674	0.0048	0.7996	0.7962	0.0034
1	8.0	0.0025	1.0045	1.0010	0.0035	0.9260	0.9210	0.0050	0.8444	0.8409	0.0035
1 1/8	7.0	0.0024	1.1298	1.1261	0.0037	1.0401	1.0346	0.0055	0.9468	0.9431	0.0037
1 1/4	7.0	0.0024	1.2550	1.2511	0.0039	1.1655	1.1596	0.0059	1.0720	1.0681	0.0039
1 3/8	6.0	0.0023	1.3803	1.3762	0.0041	1.2758	1.2695	0.0063	1.1669	1.1628	0.0041
1 1/2	6.0	0.0023	1.5055	1.5012	0.0043	1.4013	1.3945	0.0068	1.2921	1.2878	0.0043
1 5/8	5.0	0.0022	1.6308	1.6263	0.0045	1.5054	1.4982	0.0072	1.3747	1.3702	0.0045
1 3/4	5.0	0.0022	1.7559	1.7513	0.0046	1.6308	1.6232	0.0076	1.4998	1.4952	0.0046
1 7/8	4.5	0.0021	1.8812	1.8764	0.0048	1.7421	1.7341	0.0080	1.5966	1.5918	0.0048
2	4.5	0.0021	2.0064	2.0014	0.0050	1.8675	1.8591	0.0084	1.7218	1.7168	0.0050
2 1/8	4.5	0.0021	2.1316	2.1265	0.0051	1.9930	1.9842	0.0088	1.8470	1.8419	0.0051
2 1/4	4.0	0.0020	2.2568	2.2515	0.0053	2.1006	2.0914	0.0092	1.9366	1.9313	0.0053
2 3/8	4.0	0.0020	2.3819	2.3765	0.0054	2.2260	2.2164	0.0096	2.0617	2.0563	0.0054
2 1/2	4.0	0.0020	2.5071	2.5016	0.0055	2.3514	2.3415	0.0099	2.1869	2.1814	0.0055
2 5/8	4.0	0.0020	2.6323	2.6266	0.0057	2.4768	2.4665	0.0103	2.3121	2.3064	0.0057
2 3/4	3.5	0.0019	2.7575	2.7517	0.0058	2.5794	2.5687	0.0107	2.3916	2.3858	0.0058
2 7/8	3.5	0.0019	2.8826	2.8767	0.0059	2.7047	2.6937	0.0110	2.5167	2.5108	0.0059
3	3.5	0.0019	3.0077	3.0017	0.0060	2.8301	2.8187	0.0114	2.6418	2.6358	0.0060

* The minimum pitch diameter is increased when the nut is incorrect in pitch by the amount compensating for such error given in Table III.

Tolerances on Pitch and Pitch Diameter. — In regard to errors in pitch and pitch diameter, it should be understood that with an angular thread the error in pitch manifests itself not only in the direction of the axis of the screw, but also at right angles to the

Table III. Allowances to Compensate for Errors in Pitch of British Standard Whitworth Screw Threads

Nominal Diameter, of Screw, Inches	Allowances in Pitch Diameter to Compensate for Errors in Pitch of						
	±0.0005 Inch per Inch	±0.0010 Inch per Inch	±0.0015 Inch per Inch	±0.0020 Inch per Inch	±0.0025 Inch per Inch	±0.0030 Inch per Inch	±0.0035 Inch per Inch
1/4	0.0003	0.0005	0.0008	0.0010	0.0013	0.0015	0.0018
5/16	0.0003	0.0006	0.0009	0.0013	0.0016	0.0019	0.0022
3/8	0.0004	0.0008	0.0011	0.0015	0.0019	0.0023	0.0026
7/16	0.0004	0.0009	0.0013	0.0018	0.0022	0.0026	0.0031
1/2	0.0005	0.0010	0.0015	0.0020	0.0025	0.0030	.....
9/16	0.0006	0.0011	0.0017	0.0023	0.0028	0.0034	.....
5/8	0.0006	0.0013	0.0019	0.0025	0.0031	0.0038	.....
11/16	0.0007	0.0014	0.0021	0.0028	0.0034	0.0041	.....
3/4	0.0008	0.0015	0.0023	0.0030	0.0038	0.0045	.....
13/16	0.0008	0.0016	0.0024	0.0033	0.0041	0.0049	.....
7/8	0.0009	0.0018	0.0026	0.0035	0.0044	0.0053	.....
15/16	0.0009	0.0019	0.0028	0.0038	0.0047	.....	.....
1	0.0010	0.0020	0.0030	0.0040	0.0050	.....	.....
1 1/8	0.0011	0.0023	0.0034	0.0045	0.0056	.....	.....
1 1/4	0.0013	0.0025	0.0038	0.0050	0.0063	.....	.....
1 3/8	0.0014	0.0028	0.0041	0.0055	0.0069	.....	.....
1 1/2	0.0015	0.0030	0.0045	0.0060	0.0075	.....	.....
1 5/8	0.0016	0.0033	0.0049	0.0065	0.0081	.....	.....
1 3/4	0.0018	0.0035	0.0053	0.0070	0.0088	.....	.....
1 7/8	0.0019	0.0038	0.0056	0.0075	0.0094	.....	.....
2	0.0020	0.0040	0.0060	0.0080	0.0100	.....	.....
2 1/8	0.0021	0.0043	0.0064	0.0085	0.0106	.....	.....
2 1/4	0.0023	0.0045	0.0068	0.0090	.....	.....	.....
2 3/8	0.0024	0.0048	0.0071	0.0095	.....	.....	.....
2 1/2	0.0025	0.0050	0.0075	0.0100	.....	.....	.....
2 5/8	0.0026	0.0053	0.0079	0.0105	.....	.....	.....
2 3/4	0.0028	0.0055	0.0083	0.0110	.....	.....	.....
2 7/8	0.0029	0.0058	0.0086	0.0115	.....	.....	.....
3	0.0030	0.0060	0.0090	0.0120	.....	.....	.....

axis. Therefore, if an error in pitch is tolerated, a corresponding allowance should be made in the pitch diameter to compensate for the transverse effect of the pitch error introduced. If the limits for pitch diameter are determined by Formulas (11) and (12), respectively, as given in the following, which are intended to cover both the errors of that element and the allowance re-

quired to compensate for the transverse effect of pitch error, it follows that the error in pitch must be limited to such an amount that the corresponding allowance in pitch diameter is never greater than the tolerances given. The maximum permissible error in pitch, which as previously explained is connected with the tolerance on the pitch diameter, is determined by the following formulas, the thickness of the nut being assumed to be equal to the diameter of the bolt:

Tolerance in pitch per inch of length of thread in nut for British standard Whitworth thread $= \frac{\pm 0.0025}{\sqrt[4]{D}}$. (9)

Tolerance in pitch per inch of length of thread in nut for British standard fine screw threads $= \frac{\pm 0.0015}{\sqrt[4]{D}}$. (10)

Applying Formula (9) for a British standard Whitworth $\frac{1}{4}$-inch bolt, the actual error permissible in the length of thread in the nut will be found to be less than ± 0.001 inch.

The tolerances on the pitch diameter, which include in each case the allowances made to compensate for the maximum pitch error, are determined by the formulas given in the following:

Tolerance on pitch diameter of British standard Whitworth thread $= 0.005 \sqrt[4]{D^3}$. (11)

Tolerance on pitch diameter of British standard fine threads $= 0.003 \sqrt[4]{D^3}$. (12)

In the case of a bolt of incorrect pitch, the pitch diameter must be reduced by the amount necessary to compensate for the pitch error; that is, the pitch diameter requires an allowance for this purpose. Thus the tolerances on the pitch diameter and pitch are linked together, so that, if the pitch is correct, the tolerance on the pitch diameter has the full value given in Table I, but if the pitch is in error, the permissible limits or variations in pitch diameter are reduced by the allowance given in Table III. In the case of a nut, the minimum pitch diameter is increased by the allowance given in Table III. For instance, in the case of bolts having a known pitch error, the maximum pitch diameter given in Table I must be decreased an amount equal to that

given in Table III, the minimum pitch diameter remaining the same. For example, in calculating the amount of allowance necessary in the pitch diameter for a British Whitworth 1-inch bolt having, say, a pitch error of +0.0012 inch per inch, the amount of compensation, as found by interpolation from Table III, is 0.0024 inch, so that the limits on the pitch diameter of the bolt are:

Maximum pitch diameter = 0.9200 − 0.0024 = 0.9176 inch;

Minimum pitch diameter (unchanged) = 0.9150 inch.

For a 1-inch British standard Whitworth nut having the same pitch error, the changes in the pitch diameter are:

Maximum pitch diameter (unchanged) = 0.9260 inch;

Minimum pitch diameter = 0.9210 + 0.0024 = 0.9234 inch.

Table IV. Tolerances on Included Angle of Screw Threads (The Engineering Standards Committee)

Form of Thread	Range of Size, Nominal Diameter, Inches	Tolerance on Included Angle, Degrees
British Standard Whitworth Thread....	¼ to 9/16	±1.5
	5/8 to 2⅛	±1.0
	2¼ to 3	±0.5
British Standard Fine Thread.....	¼ to 1 3/16	±1.5
	7/8 to 3	±1.0

Tolerances for Angle of Thread. — As mentioned, the angle of the thread ranks in importance with the pitch and the pitch diameter. Errors in the angle may be such as to prevent interchangeability, so that it is necessary to establish limits for the included angle of the thread. The tolerances on British standard Whitworth and British standard fine threads are given in Table IV. Reference to this table will show that the coarser the pitch, the smaller is the permissible error in the included angle.

Tolerances on U. S. Standard Screw Threads. — Several concerns in the United States have adopted tolerances for their own use, some of which have been compiled and put into convenient form. Table V gives tolerances for U. S. standard

screws and gages for loose fits, and Table VI gives those for close fits. Reference to these two tables will show that the tolerances on the tapped hole and the tolerances on the pitch diameter of the gage are the only two factors that are materially changed. The loose-fit limits are, in most cases, twice the close-fit limits. It will also be noticed that the manufacturing tolerances on the pitch diameter of the gage are given as 0.0002 inch up to 1 inch in diameter and as 0.00025 inch for 1 inch and over. The gage pitch diameters are made greater than the diameter of the maximum and minimum tapped holes, so as to provide for wear, especially on the "go" end of the gage.

Tolerances on Reference Thread Gages. — In the measurement and inspection of threaded parts, even greater care is necessary than in gaging a plain hole or shaft. The chief reason for this is that a thread has so many elements that must be taken into consideration that a careful study of the conditions to be met is necessary. Master or reference screw gages should be made much more accurately than working or inspection gages; and owing to this fact, master gages, as a rule, are left soft in order to eliminate any chance for warpage or shrinkage in hardening.

For reference thread gages, the tolerances in pitch are generally given for a length of one inch, and vary from 0.0005 inch per inch for threads coarser than ten threads per inch, to 0.001 inch per inch for finer pitches. The tolerance on the pitch diameter, as has been mentioned, is also governed to a certain extent by the tolerance on the pitch. Most manufacturers, however, endeavor to make the pitch diameter to tolerances of $\pm$0.0001 inch. If the error in pitch is uniform, that is, equally distributed for the length of the thread, the tolerance on the pitch diameter may be very small. For example, on a gage with 10 threads per inch, the error of 0.0005 inch is distributed over ten threads, making the average error in pitch only 0.00005 inch.

The angle of the thread is one of the three elements that affect the pitch diameter in a manner similar to the pitch, and where close tolerances are adhered to on the pitch diameter it is essential that the angle be held to very close limits. The coarser

Table V. Tolerances on Pitch Diameters of U. S. Standard Screws, Taps, and Gages (Loose Fit Tolerances)

Nominal Diameter of Screw, Inches	Number of Threads per Inch	Basic or Pitch Diam. of Max. Screw	Pitch Diam. of Min. Screw	Tolerance between Max. and Min. Pitch Diam. of Screw	Tolerance between Max. Screw and Min. Pitch Diam. of Tap	Tapped Hole, Pitch Diameter		Tolerance on Tapped Hole	Gage, Pitch Diameter		Difference between "Go," and "Not Go" Ends of Gage	Difference between Min. Gage and Max. Screw
						Max.	Min.		Max.	Min.		
¼	20	0.2175	0.2160	0.0015	0.0005	0.2200	0.2180	0.0020	0.22020	0.21820	0.0020	0.00070
5/16	18	0.2764	0.2748	0.0016	0.0006	0.2790	0.2770	0.0020	0.27920	0.27720	0.0020	0.00080
3/8	16	0.3344	0.3327	0.0017	0.0006	0.3380	0.3350	0.0030	0.33820	0.33520	0.0030	0.00080
7/16	14	0.3911	0.3892	0.0019	0.0009	0.3950	0.3920	0.0030	0.39520	0.39220	0.0030	0.00110
½	13	0.4501	0.4481	0.0020	0.0009	0.4540	0.4510	0.0030	0.45420	0.45120	0.0030	0.00110
9/16	12	0.5084	0.5063	0.0021	0.0010	0.5124	0.5094	0.0030	0.51260	0.50960	0.0030	0.00120
5/8	11	0.5660	0.5638	0.0022	0.0010	0.5700	0.5670	0.0030	0.57020	0.56720	0.0030	0.00120
11/16	11	0.6285	0.6262	0.0023	0.0010	0.6325	0.6295	0.0030	0.63270	0.62970	0.0030	0.00120
¾	10	0.6851	0.6827	0.0024	0.0010	0.6901	0.6861	0.0040	0.69030	0.68630	0.0040	0.00120
13/16	10	0.7476	0.7451	0.0025	0.0010	0.7526	0.7486	0.0040	0.75280	0.74880	0.0040	0.00120
7/8	9	0.8029	0.8004	0.0025	0.0011	0.8080	0.8040	0.0040	0.80820	0.80420	0.0040	0.00130
15/16	9	0.8654	0.8627	0.0027	0.0011	0.8705	0.8665	0.0040	0.87070	0.86670	0.0040	0.00130
1	8	0.9188	0.9159	0.0029	0.0012	0.9270	0.9220	0.0050	0.92725	0.92025	0.0050	0.00145
1⅛	7	1.0322	1.0292	0.0030	0.0012	1.0384	1.0334	0.0050	1.03865	1.03365	0.0050	0.00145
1¼	7	1.1572	1.1541	0.0031	0.0012	1.1634	1.1584	0.0050	1.16365	1.15865	0.0050	0.00145
1⅜	6	1.2668	1.2635	0.0033	0.0013	1.2741	1.2681	0.0060	1.27435	1.26835	0.0060	0.00155
1½	6	1.3918	1.3884	0.0034	0.0013	1.3991	1.3931	0.0060	1.39935	1.39335	0.0060	0.00155

Table VI. Tolerances on Pitch Diameters of U. S. Standard Screws, Taps, and Gages (Close Fit Tolerances)

Nominal Diameter of Screw, Inch	Number of Threads per Inch	Basic or Pitch Diam. of Max. Screw	Pitch Diam. of Min. Screw	Tolerance between Max. and Min. Pitch Diam. of Screw	Tolerance between Max. Screw and Min. Pitch Diam. of Tap	Tapped Hole, Pitch Diameter		Tolerance on Tapped Hole	Gage, Pitch Diameter		Difference between "Go," and "Not Go" Ends of Gage	Difference between Min. Gage and Max. Screw
						Max.	Min.		Max.	Min.		
¼	20	0.2175	0.2160	0.0015	0.0005	0.2190	0.2180	0.0010	0.21920	0.21820	0.0010	0.00070
5/16	18	0.2764	0.2748	0.0016	0.0006	0.2780	0.2770	0.0010	0.27820	0.27720	0.0010	0.00080
3/8	16	0.3344	0.3327	0.0017	0.0006	0.3365	0.3350	0.0015	0.33670	0.33520	0.0015	0.00080
7/16	14	0.3911	0.3892	0.0019	0.0009	0.3935	0.3920	0.0015	0.39370	0.39220	0.0015	0.00110
½	13	0.4501	0.4481	0.0020	0.0009	0.4525	0.4510	0.0015	0.45270	0.45120	0.0015	0.00110
9/16	12	0.5084	0.5063	0.0021	0.0010	0.5109	0.5094	0.0015	0.51110	0.50960	0.0015	0.00120
5/8	11	0.5660	0.5638	0.0022	0.0010	0.5685	0.5670	0.0015	0.56870	0.56720	0.0015	0.00120
11/16	11	0.6285	0.6262	0.0023	0.0010	0.6310	0.6295	0.0015	0.63120	0.62970	0.0015	0.00120
¾	10	0.6851	0.6827	0.0024	0.0010	0.6881	0.6861	0.0020	0.68830	0.68630	0.0020	0.00120
13/16	10	0.7476	0.7451	0.0025	0.0010	0.7506	0.7486	0.0020	0.75080	0.74880	0.0020	0.00120
7/8	9	0.8029	0.8004	0.0025	0.0011	0.8060	0.8040	0.0020	0.80620	0.80420	0.0020	0.00130
15/16	9	0.8654	0.8627	0.0027	0.0011	0.8685	0.8665	0.0020	0.86870	0.86670	0.0020	0.00130
1	8	0.9188	0.9159	0.0029	0.0012	0.9225	0.9200	0.0025	0.92275	0.92025	0.0025	0.00145
1⅛	7	1.0322	1.0292	0.0030	0.0012	1.0359	1.0334	0.0025	1.03615	1.03365	0.0025	0.00145
1¼	7	1.1572	1.1541	0.0031	0.0012	1.1609	1.1584	0.0025	1.16115	1.15865	0.0025	0.00145
1⅜	6	1.2668	1.2635	0.0033	0.0013	1.2711	1.2681	0.0030	1.27135	1.26835	0.0030	0.00155
1½	6	1.3918	1.3884	0.0034	0.0013	1.3961	1.3931	0.0030	1.39635	1.39335	0.0030	0.00155

the pitch of the thread, the smaller is the amount of error permissible in the angle, and for this element the tolerances range from $\pm \frac{1}{10}$ degree for the coarser pitches to $\pm \frac{1}{4}$ degree for the finer pitches.

Manufacturing Tolerances on Working and Inspection Thread Gages. — As working and inspection thread gages must be hardened if satisfactory service is to be obtained from them, and as they wear much faster than reference gages, greater tolerances are permissible. As a general rule, the pitch is held to a tolerance of ±0.001 inch per inch of length, and the pitch diameter is governed to a certain extent by the tolerance on the work. When the working and inspection gages are laid out in connection with the limit system of manufacture, the tolerances permitted on the "go" and "not go" ends of the gage should be laid out with respect to the tolerances on the work. For instance, the maximum or " not go " end of the plug should be made larger than the maximum hole by an amount equal to the maximum manufacturing tolerance permissible on the gage, and the " go " end should be made larger than the minimum tapped hole by an amount equal to the manufacturing tolerance permitted on the gage. When the gage is new, it will not enter the minimum tapped hole, but as a tap in most cases cuts larger than its actual size, the gage will enter holes slightly larger than those cut with a minimum tap. Another advantage of this practice lies in the fact that a great amount of wear is allowed for in the gage before it is worn too small. The manufacturing tolerances permitted on the pitch diameter of thread gages vary from +0.0001 to +0.00025 inch, depending upon the size and pitch of the gage.

The tolerance on the included angle of the thread is generally made to practically the same limits as for the reference gages. As any variations in the included angle of the thread directly affect the pitch diameter, it is imperative that errors in the included angle of the thread be reduced to a minimum.

Reference Thread Gages. — Reference thread gages are made either from a good grade of tool steel and left soft or from machinery steel carburized and hardened. The soft gages, when

carefully used, are more accurate than the hardened ones, owing to the elimination of warpage or distortion, which usually takes place during the carburizing and hardening process. Reference thread gages of comparatively coarse pitch can be ground with a diamond-charged lap, and when this practice is followed, the hardened reference gage is superior to the soft one. Ordinary lapping, however, cannot be depended upon to correct the lead of a distorted gage; for this reason, reference thread gages are usually left soft.

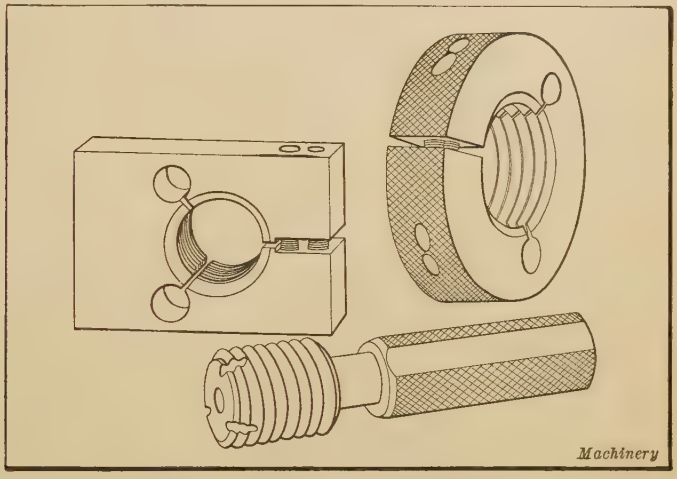


Fig. 3. Reference Thread Gages

A common form of reference thread gage consists of a plug and templet, as shown in Fig. 3. Here two forms of templets are shown, one of rectangular and the other of circular form. Both types are adjustable and are set to the master plug. In manufacturing plants where the limit system is employed, these types of reference thread gages are of little or no value, because they cannot be used for setting the working or inspection gages, which are not set to a standard size but provide for tolerances on the work. In addition, a ring thread gage is of little value in testing the thread on a screw, as it is difficult to determine what element of the screw is in error.

In making reference screw gages for the U. S. standard form

of thread, a flat of one-eighth the pitch is provided on the outside diameter of the plug, whereas the bottom is made to a sharp V-shape in order to clear fine chips and dirt that may collect in the threads. The front end of the plug is also provided with three angular grooves to collect dirt and dust. The crest of the threads in the ring is made with a flat of one-eighth the pitch and the bottom is made to a sharp V the same as in the plug.

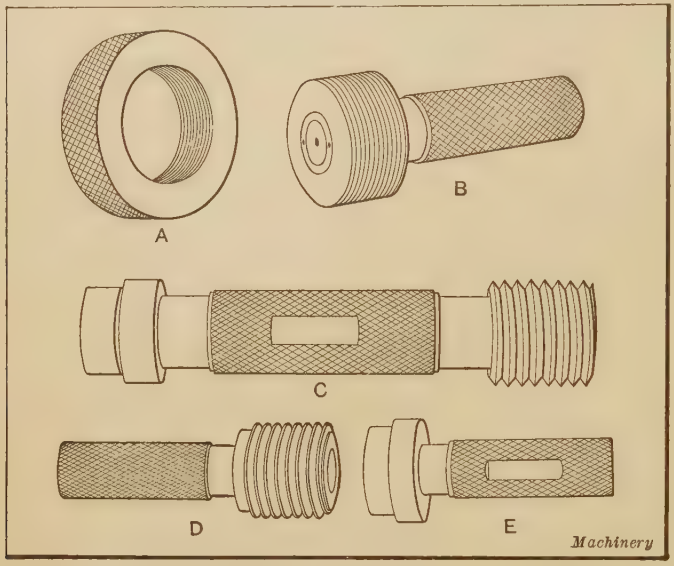


Fig. 4. Various Forms of Reference Gages for Whitworth Standard Threads

Fig. 4 shows a group of reference gages for British Whitworth standard threads. Ring *A* and plug *B* are left soft, and are used for reference purposes only. The form shown at *C* is provided with a threaded end and a plain cylindrical end having two shoulders, which represent the root and the outside diameter; *D* and *E* show two reference plugs that fill the same function as plug *C*. Reference gages for use in connection with the limit system of manufacture should be made as shown in Fig. 2, Chapter III. This enables the inspection and working gages to be readily checked to determine when they are worn beyond the tolerances.

Pipe Threads. — There are two common forms of pipe-thread standards in use, *viz.*, the Briggs standard and the British standard, as shown at *A* and *B* in Fig. 5. The Briggs standard pipe thread is made with an angle of 60 degrees. It is slightly rounded at the top and the bottom, so that the depth of the thread, instead of being equal to that of a sharp V-thread (0.866 × pitch), is only four-fifths of the pitch, or equal to 0.8 ÷ (number of threads per inch). The difficulty of producing a thread with rounded top and bottom has caused a modification to be made in the thread form, as shown in Fig. 6. Instead of rounding the bottom of the thread, it is made practically sharp, while the top is slightly flattened, the flat being carried down so that it just touches what would be the rounded part of the correct thread form. As thus modified, the formulas for the thread are:

$$d = 0.833\,p = \frac{0.833}{\text{number of threads per inch}},$$

$$f = \frac{p}{26} = \frac{1}{26 \times \text{number of threads per inch}},$$

in which p = pitch of thread;
d = depth of thread;
f = flat on top of thread.

Complete details of Briggs standard pipe threads and gage dimensions are given in standard handbooks on machine shop practice (see MACHINERY'S HANDBOOK, 5th Edition, pages 1008 and 1009).

For the length of the pipe end throughout which the screw thread continues "perfect," the following formula is used:

$$(0.8\,D + 4.8) \times \frac{1}{n}, \qquad (13)$$

in which D = outside diameter of tube, in inches;
n = number of threads per inch.

This distance is referred to as dimension *F* in Fig. 5. Located back of the perfect threads is a section including two threads having a perfect bottom and a flat top; and still farther

back is a portion having imperfect threads, which is formed by the chamfer or bell-mouth in the threading die. The perfect threads are cut on a taper equal to $\frac{3}{4}$ inch to the foot, or $\frac{1}{16}$ inch to the inch on the diameter.

British Standard Pipe Threads. — The form of thread is that of the Whitworth system; the sides of the thread form an angle of 55 degrees with each other, and the top and bottom of the threads are rounded to a radius equal to 0.1373 × the pitch of the thread. For taper pipe threads, the taper is $\frac{3}{4}$ inch per foot, or $\frac{1}{16}$ inch per inch, measured on the diameter. This

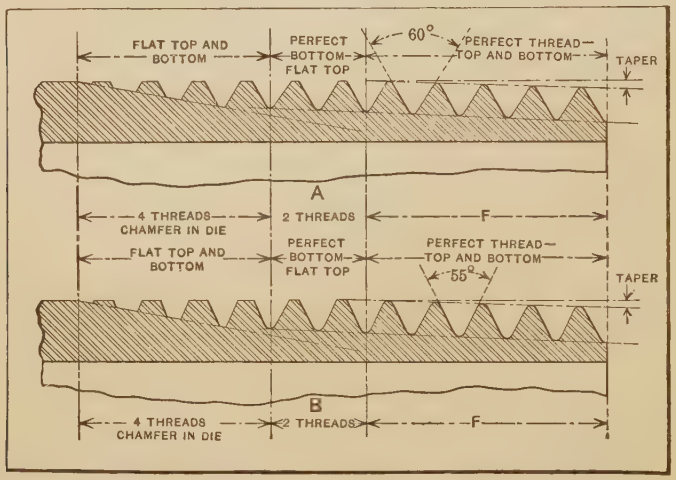


Fig. 5. Briggs and Whitworth Standard Forms of Pipe Threads

system has been approved by the Engineering Standards Committee as the standard pipe thread system in Great Britain, and is known as the "British Standard Pipe Thread for Iron and Steel Pipes and Tubes."

In the British standard form of pipe thread shown at *B* in Fig. 5, the diameter of the screw is made to such size that the coupling or joint can be screwed on by hand to within four or five threads of the end of the threaded portion. The length of threads on standard pipe ends is found by the following formula:

$$L = \sqrt[5]{D^2} - \tfrac{1}{8}\,\text{inch}, \qquad (14)$$

in which L = length of thread, in inches;

D = nominal bore of pipe, in inches.

The length of the thread in the coupling or joint should not be made less than twice the length of the thread on the pipe ends, and the length of the thread at the end of a fitting must not be made less than the nominal length of the thread on the corresponding end of the pipe.

Briggs Pipe Thread Gages. — The following information relating to standards for Briggs pipe thread gages has been abstracted from the report of a Committee on the Standardization of Pipe Threads appointed by the American Society of Mechanical Engineers. The purpose of the Committee on Standardization of Pipe Threads was to fix manufacturing limits for the use of the Briggs standard pipe thread gages when tapping fittings or flanges, so that pipe cut to the Briggs standard might always enter a definite number of turns. Although the Briggs standard is used almost universally for pipe threads in the United States, the method of its use for female threads has not been established, in that no determinations have ever been made of the standard depths to which hand plug gages should enter. This has resulted in much confusion in the past, inasmuch as pipe threaded to the Briggs standard is liable to vary in the number of threads it would screw into fittings tapped at different shops. This tendency is so marked that pipe fitting is handled in practically all cases by sending the flanges to the shop where the pipe is cut, to be sure of satisfactory results.

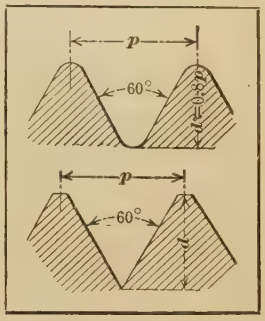


Fig. 6. Briggs Pipe Thread

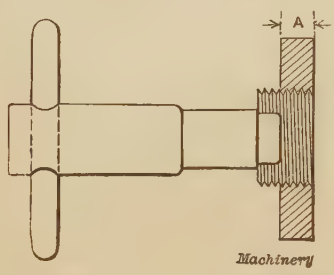
This matter is conceded to be a simple one in that all it requires is an agreement among the manufacturers of fittings as to the point at which a ring should be attached to the gage, to establish, when the gage is inserted by hand, the proper depth of the thread. To this end, the committee met in conference

with representatives of the manufacturers and also of the committee of the Society on International Standards for Pipe Threads. The conclusions reached were as follows:

The gages shall consist of one plug and one ring gage of each size.

The plug gage shall be the Briggs standard pipe thread as adopted by the manufacturers of pipe fittings and valves, and recommended by the American Society of Mechanical Engineers in 1886. The plug is to have a flat or notch indicating the distance that it shall enter the ring by hand.

Table VII. Standard Thickness of Pipe Ring Gages



Pipe Size	Thickness A, Inch	Pipe Size	Thickness A, Inch
⅛	0.180	1	0.400
¼	0.200	1¼	0.420
⅜	0.240	1½	0.420
½	0.320	2	0.436
¾	0.339	2½	0.682

Pipe Size	Thickness A, Inches
3	0.766
3½	0.821
4	0.844
4½	0.875
5	0.937
6	0.958
7	1.000
8	1.063
9	1.130
10	1.210
12	1.360
14	1.562
15	1.687
16	1.812
18	2.000
20	2.125
22	2.250
24	2.375
.....	.....

The ring gage is to be known as the American Briggs standard adopted by the Manufacturers' Standardization Committee in 1913, and recommended by the American Society of Mechanical Engineers, the committee on International Standard for Pipe Threads, and the Pratt & Whitney Co., manufacturer of gages. The thickness of the ring is given in Table VII. It shall be flush with the small end of the plug. This will locate the end of the flat on the plug flush with the large side of the ring.

When using the plug gage, as shown in the illustration accompanying the table, the flat indicates the exact size, and the allowable limits should be one thread large or small. When using the ring gage, the male threads are to size when the plug gage is flush with the small end of the ring. The allowable limits are one thread large or small. A set of these gages to be known as the "American Briggs Standard for Pipe Threads" is deposited with the Bureau of Standards at Washington, D. C.

Thread Micrometers. — The simplest instrument and the one most commonly used for measuring screw threads where only a few are to be inspected is the micrometer caliper. In order to use the micrometer caliper for this work, and especially

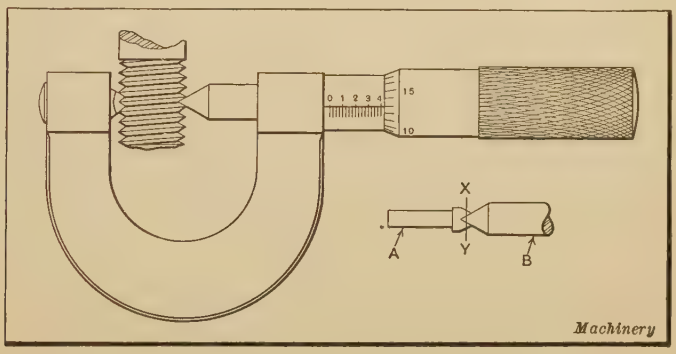


Fig. 7. Screw Thread Micrometer

for measuring the pitch diameter and angle of thread, it is necessary either to provide the instrument with special measuring points or to make use of the wire method.

One of the many methods of measuring in the angle of the thread is by use of the thread micrometer shown in Fig. 7. The fixed anvil *A* is V-shaped, so as to fit over the thread, while the movable point *B* is cone-pointed, so that it may enter the space between any two threads. The extreme end of the cone is removed so as not to come into contact with the bottom of the thread. The anvil is also provided with a clearance at the bottom of the V-groove so that both the anvil and the cone-pointed spindle will come in contact only with the

sides of the thread. When the cone point and the anvil are in contact, the zero line on the thimble represents a line drawn through the plane $X\,Y$. If the caliper is opened, say to 0.375 inch, it means that the two planes are 0.375 inch apart. The cone point is adapted for measuring all pitches, but the fixed anvil is limited in its capacity, and to cover all pitches it is necessary to provide different anvils for the various pitches.

To find the theoretical pitch diameter that is measured by this micrometer, it is necessary to deduct the single depth of the thread from the outside diameter. Expressed in a formula for the various types of threads, the pitch diameter equals:

For sharp V-thread:

$$D = d - \frac{0.866}{N}.$$

As it is not practicable to make a V-thread theoretically sharp, the outside will measure less than the nominal size, the pitch diameter remaining the same.

For U. S. and A. S. M. E. standard threads:

$$D = d - \frac{0.6495}{N},$$

For Whitworth standard thread:

$$D = d - \frac{0.640}{N},$$

in which D = caliper reading or pitch diameter;
d = nominal outside diameter of thread;
N = number of threads per inch.

In the thread micrometer shown in Fig. 7, the offset of the center line of the anvil and cone-pointed spindle necessary to take care of the helix angle of the thread is provided for by holding the anvil so that it is free to rotate, and by employing various anvils for different pitches of threads. In the micrometer shown in Fig. 8, the anvil is mounted in a slide and the amount of offset is controlled by a micrometer. To measure a thread of a certain pitch, the anvil is set off center an amount equal to one-half the pitch of the thread being measured.

Micrometer having Ball Points. — The regular screw-thread micrometer has the disadvantage of being delicately constructed and of requiring careful and frequent adjustment. It is preferable to use the standard screw-thread micrometer for reference only and to measure screw plugs or screws by means of the standard micrometer fitted with different types of points; a micrometer so arranged is then used to *compare* the thread measured with a standard gage.

There are many types of points used; the illustration accompanying Table VIII shows three. The type shown at *A* is

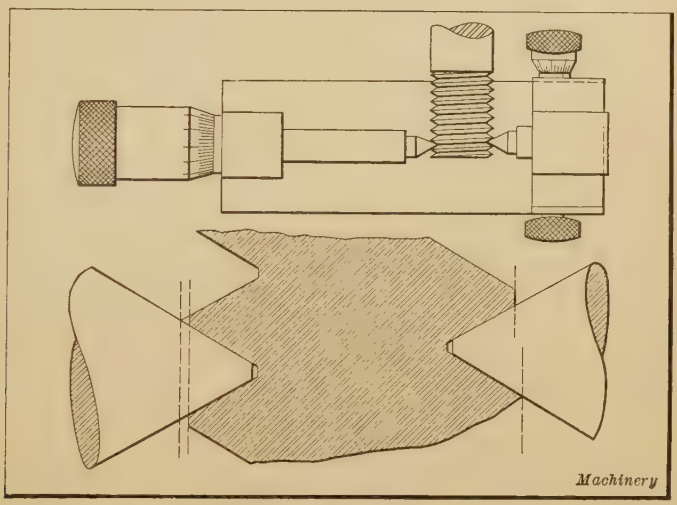
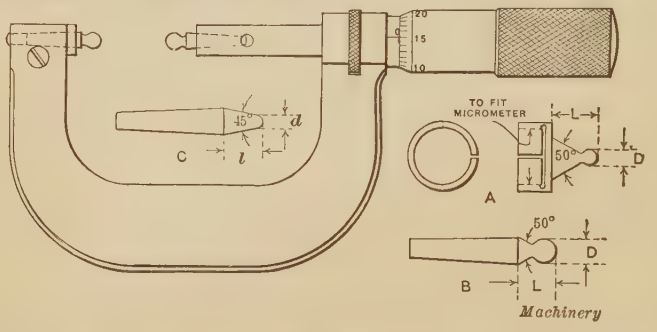


Fig. 8. Adjustable Thread Micrometer

made to slip over both measuring points of the micrometer, and to obtain satisfactory results must be carefully made. However, these points, as a rule, do not fit solidly over the anvil and spindle of the micrometer even if they are split, and are apt to cause errors in measurements. Better types of points are shown at *B* and *C*. The ball point shown at *B* can be used for measuring threads as fine as 16 per inch. When a thread is finer than this, the neck becomes so small that there is not sufficient strength, and the point is formed as shown at *C*. This point can be used for measuring threads as fine as 72

threads per inch. In Table VIII, the first column gives the number of threads for which the diameter of the point has been calculated, and the second column gives the pitches for which this size of point can be used. These points will fit approximately halfway between the top and root of the thread in the U. S. standard screw or threaded plug. They are used for reference only, and are set by means of a standard screw plug.

Table VIII. Dimensions of Ball Points Used in Measuring Threads



No. of Threads per Inch Calculated for	No. of Threads per Inch Used for	D, Inch	L, Inch	No. of Threads per Inch Calculated for	No. of Threads per Inch Used for	d, Inch	l, Inch
3½	3½	0.164	9/32	18	18–20	0.031	3/32
4	4	0.143	9/32	22	22	0.026	1/16
4½	4½	0.127	9/32	24	24–26	0.023	1/16
5	5	0.111	9/32	28	27–30	0.020	1/16
6	6	0.095	5/32	32	32–34	0.018	1/16
7	7	0.081	5/32	36	36–38	0.016	1/16
8	8–9	0.070	5/32	40	40–46	0.014	1/16
10	10–11	0.059	3/32	52	48–60	0.011	1/16
12	12–13	0.049	3/32	66	62–72	0.0086	1/16
14	14–15	0.042	3/32	.....	.....	.....	....
16	16	0.036	3/32	.....	.....	.....	....

They do not check the angle of the thread, as does a regular screw-thread micrometer, but the angle may be obtained by using different sizes of points, and comparing the size near the root of the thread with one size of ball, using a larger ball for the pitch diameter, and a still larger one near the top. If

these three measurements agree with the standard gage, the angle of thread is correct.

One-wire System of Measuring Screw Threads. — The pitch diameter of screw threads may be measured with an ordinary micrometer and one wire arranged as indicated in Fig. 9. If the outside diameter of the screw is large or small, allowance must be made for this in taking the measurement. If the screw is oversize, one-half the amount that it is oversize must be added to the dimensions obtained by the formulas. If it is undersize, one-half the amount that it is undersize must be deducted. One wire is easier to handle than three wires, but is not as generally used, because the method is less accurate. This method, however, can be used on coarse-pitch threads where the micrometer spindle will not reach from one thread to the next, which is necessary with the three-wire system. Assuming that D is the micrometer reading over the wire when the pitch diameter is correct, and T. P. I. represents threads per inch, the formulas for measuring with a micrometer and one wire are:

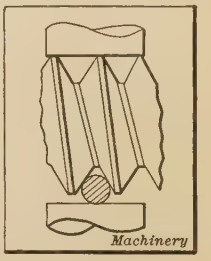


Fig. 9. Diagram illustrating One-wire System of measuring Screw Threads

For sharp V-thread:

$$D = 1.5 \times \text{diameter of wire} - \frac{0.866}{\text{T. P. I.}} + \text{standard outside diameter.}$$

For U. S. standard thread:

$$D = 1.5 \times \text{diameter of wire} - \frac{0.7577}{\text{T. P. I.}} + \text{standard outside diameter.}$$

For standard Whitworth thread:

$$D = 1.583 \times \text{diameter of wire} - \frac{0.8004}{\text{T. P. I.}} + \text{standard outside diameter.}$$

The size of wire is governed by the pitch and form of thread. The best size to use is about two-thirds the pitch. Mistakes can easily be made if too large a wire is used. A wire smaller

than six-tenths or larger than nine-tenths the pitch should not be used.

Thread Measuring Indicator Using One Wire. — A thread measuring device for comparing screws with gages or working gages with master gages is shown in Fig. 10. This device was designed to eliminate the personal element in measuring threaded parts or gages, as it has been found that in using thread micrometers, whether equipped with conical or ball points, measurements made by different men, or even by the same man,

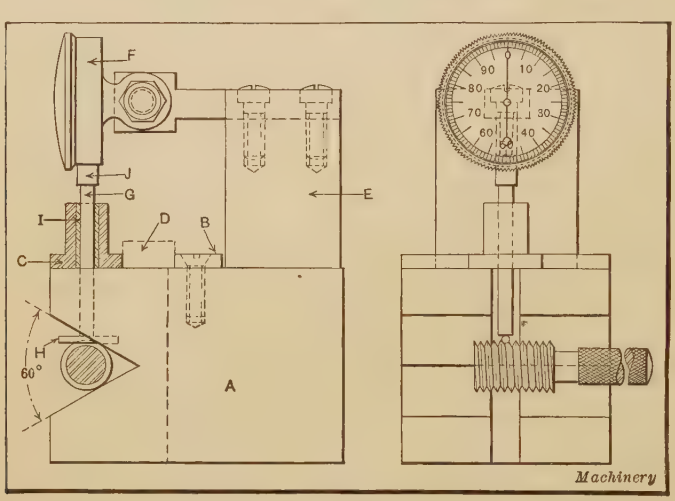


Fig. 10. Another Method of using One-wire System for Thread Measurement

differ at times, and show variations of as much as from 0.0001 to 0.0003 inch. The same objection as mentioned in connection with Fig. 9 — that the condition of the outside diameter of the thread is likely to affect the accuracy of the reading — applies also to this tool.

Referring to Fig. 10, the tool consists of a block *A* with a 60-degree groove in it and with a straightedge *B* fastened to the top face by screws and dowels. The straightedge is so placed that the attachment *C* can be adjusted to bring its axis to line up with the axis of the thread plug being measured, by inserting a standard measuring block *D*. On top of block

A is another block *E* which carries a dial indicator reading to 0.0001 inch. Attachment *C* carries rod *G*, which extends down through the slot cut in block *A* and rests upon a wire *H* laid between the threads of the work. To prevent wire *H* from dropping out, rod *G* is magnetized; and to prevent the magnetism from interfering with the free movement of rod *G*, the rod is surrounded by a brass bushing *I*, and is held from dropping out by a set-screw, not shown. The wire *H* is made of drill rod and is hardened and ground to exact size; an assortment of wires is provided for the different pitches of threads to be measured. A wire having a diameter equal to two-thirds or three-quarters of the pitch works satisfactorily, but to facilitate calculation, it is well to use wires with diameters in an even number of thousandths, 0.120, for instance, instead of 0.125 inch.

If it is desired to compare a piece of threaded work with a standard, the standard is first clamped in the block *A*; then a size-block *D*, equal in thickness to the diameter of the standard, is inserted between attachment *C* and straightedge *B*. Rod *G* is then brought to bear on a wire laid in the threads of the standard, and the indicator spindle is brought over in contact with rod *G* and a reading taken. The same process is repeated after removing the standard and inserting the piece to be measured; the difference between the two pieces will then be read off on the indicator in 0.0001 inch.

This device may also be used for originating measurements by replacing the dial indicator with a micrometer spindle, which carries an indicating needle, thus eliminating the necessity for "feel" on the part of the inspector. For originating measurements, however, the most satisfactory way is to use a standard measuring machine.

Three-wire Method of Measuring Screw Threads. — The three-wire method of measuring screw threads has the advantage over the one-wire method in that the outside diameter need not enter into the calculation in order to determine the pitch diameter. The three wires are arranged as shown at *A* and *B* in Fig. 11. One wire is placed in the angle of the

thread on one side of the screw or threaded plug and the other two on the opposite side; the measurement is taken over the wires with a regular micrometer. The limit of this method is reached when the pitch of the thread is such that the micrometer anvil or spindle will not reach across the two wires.

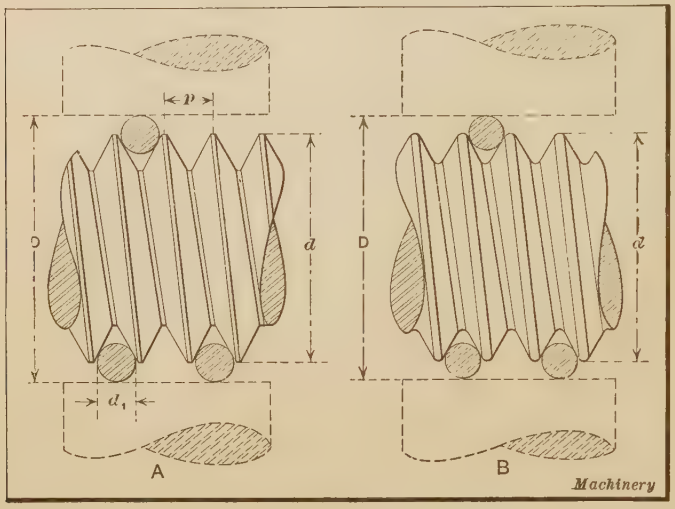


Fig. 11. Three-wire Method of measuring Screw Threads

If the pitch diameter is correct, the micrometer readings for the various forms of threads are:

For sharp V-thread:

$$D = d - 1.732\,p + 3\,d_1,$$

For U. S. and A. S. M. E. standard threads (*A*, Fig. 11):

$$D = d - 1.5155\,p + 3\,d_1,$$

For Whitworth standard thread (see *B*, Fig. 11):

$$D = d - 1.6008\,p + 3.1657\,d_1,$$

For British Association standard thread:

$$D = d - 1.7363\,p + 3.4829\,d_1,$$

For Löwenherz thread:

$$D = d - 1.75\,p + 3.2359 d_1,$$

in which

D = micrometer reading over wires;
d = standard outside diameter of screw;
d_1 = diameter of wires;
p = pitch, in inches.

Taking the U. S. standard thread formula as an example, assume that the standard outside diameter d is 0.5 inch. The number of threads per inch is 13; hence, the pitch is 0.0769. The diameter d_1 of the wires used is 0.050 inch. Then:

$$\begin{aligned} D &= 0.500 - (1.5155 \times 0.0769) + 3 \times 0.050 \\ &= 0.500 - 0.1166 + 0.150 = 0.3834 + 0.150 \\ &= 0.5334 \text{ inch.} \end{aligned}$$

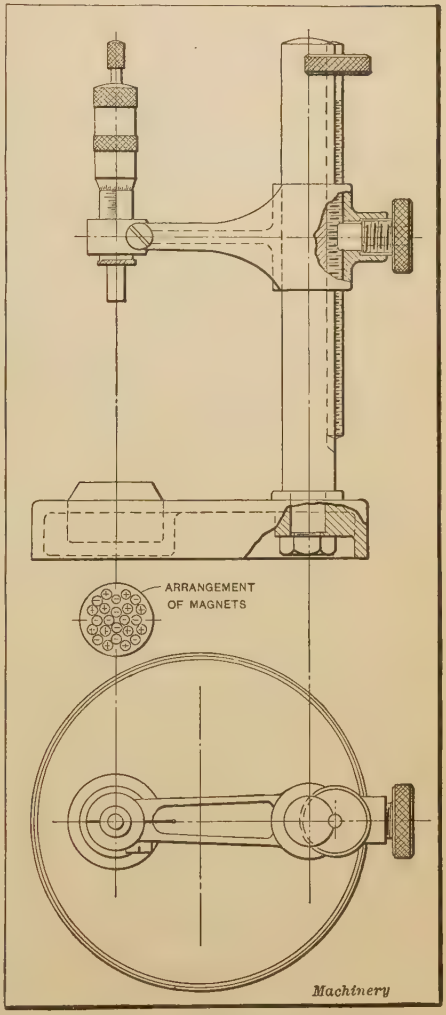


Fig. 12. Magnetized Stand for Use in measuring Threads by Three-wire Method

Methods of Using Three-wire System. — Difficulty is sometimes encountered in applying the three-wire system, owing to the necessity for retaining all three wires accurately in the grooves of the thread. One method of overcoming this objection consists in the use of a special stand, as shown in Fig. 12. This stand consists

of a cast-iron base carrying a column to which is clamped a micrometer head that is adjusted by a vertical screw. Directly beneath the micrometer head, and embedded in the base, is a

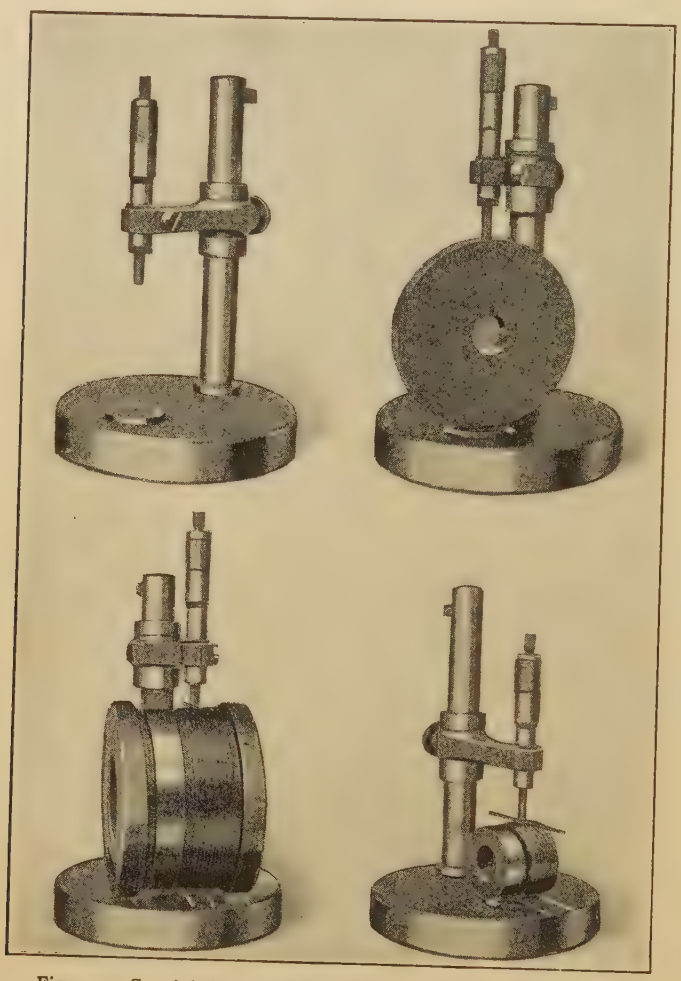


Fig. 13. Special Stand shown in Fig. 12 in Use measuring Reference Thread Gages

gun-metal bushing holder in which is placed a series of magnetized cylindrical pins arranged as shown in the plan view. These pins prevent the wires on the anvil from rolling off and

also enable them to be accurately placed. The magnets are arranged with their negative and positive poles as indicated. In applying the instrument, the micrometer is adjusted until it registers the exact size of the cylindrical reference gage, as shown in Fig. 13. Then the dimensions measured over the wires can be read off directly from the micrometer, care being taken to see that the temperatures of the reference gage and the gage being tested are the same.

Another simple but satisfactory method of applying the three-wire system is shown in Fig. 14. In this case, use is made of the Johansson standard holder and the regular thickness blocks.

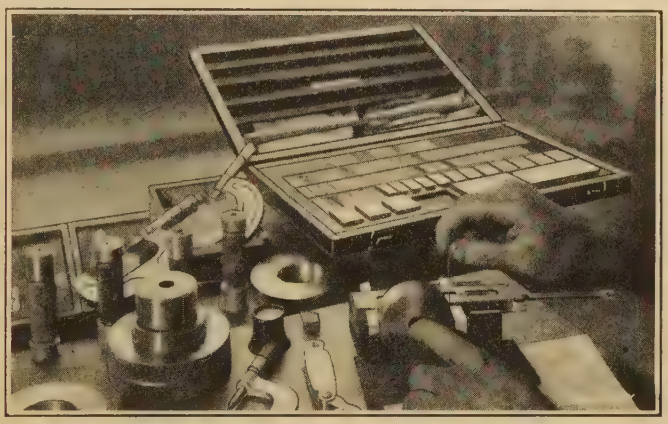


Fig. 14. Method of using Johansson Reference Blocks for Measuring Screw Threads

The holder retains two carefully ground and lapped blocks, which are spaced the required distance apart by using the regular Johansson thickness blocks. Against the face of one block two wires of the required size are placed, and the plug to be measured is then brought up against these wires. A third wire is used to test the accuracy of the work by being tried in the grooves on the opposite side. This makes a very sensitive test, as there is no pressure to consider except the weight of the small wire, which is almost negligible. It is, therefore, possible for the inspector to detect the slightest error. The limit of tolerance on this gage is 0.0002 inch.

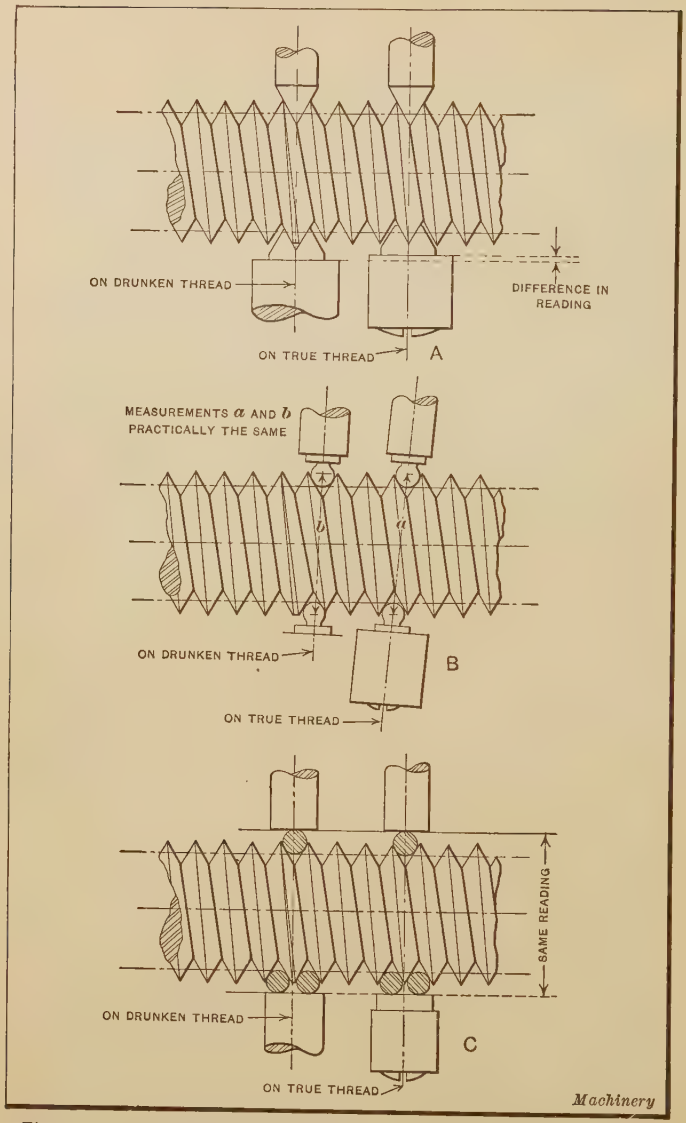


Fig. 15. Diagram illustrating Failure of Ball Point and Three-wire Method of Measurement to detect Drunken Threads

Comparison of Ball Point and Anvil Type of Thread Micrometer. —Several forms of measuring points are employed for comparing the pitch diameters of threaded work. Those used

in the Brown & Sharpe thread micrometer, shown at *A* in Fig. 15, may be used for positive measurements as well as for comparison. At *B* and *C* are illustrated other principles of measuring, the former using a ball-point micrometer and the latter three wires of suitable diameter, measured with the regular micrometer caliper. The arrangements shown at *A* and *C* may be used either for positive measurements or comparison with other threads. The device shown at *B*, however, should be used only for comparative measurements between threads of the same form.

A recent experiment proved that the method shown at *B* can only be relied upon in certain cases, even for comparative measurements, and the same holds true of that shown at *C*. The way in which this was discovered brings up an interesting point in machine-tool construction as well as in thread measuring. A manufacturer bought a lathe for cutting accurate threads, which was provided with an accurate lead-screw. A serious error, however, developed in the mounting of the machine. It was provided with a loose thrust collar between the shoulder of the lead-screw and the face of the bearing bracket which took the thrust in feeding the carriage. This thrust collar was poorly squared up, being some thousandths of an inch thicker on one side than on the other. Unfortunately, the thrust surfaces on the lead-screw in the bearing between which it was placed were also poorly faced, running out sideways to an appreciable extent. As a result, the lead-screw in revolving received an irregular endwise movement resulting from the varying positions of the untrue loose washer between its untrue thrust surfaces. The machine thus cut an irregular, or drunken, thread. This fact was brought to the attention of the makers of the machine, who measured the lead-screw with a ball-point micrometer, and also a sample screw cut by it, and pronounced it "O. K." The purchaser of the machine, however, brought out a measuring tool of the type shown at *A*, which at once indicated varying diameters in different parts of the threads on the work, giving evidence of the irregularity of which he complained. The reasons for this were evident. The ball-point micrometer shown at *B*

measured the groove cut by the thread tool; and as this is always set at the same depth and is unvarying in shape, the error was not detected. The same conditions are met with in the three-wire method shown at *C*. The lower anvil of the point at *A*, however, since it spans the abnormal thread instead of making contact with the side of the adjacent threads, indicates the irregularity by giving an increased reading for the pitch diameter.

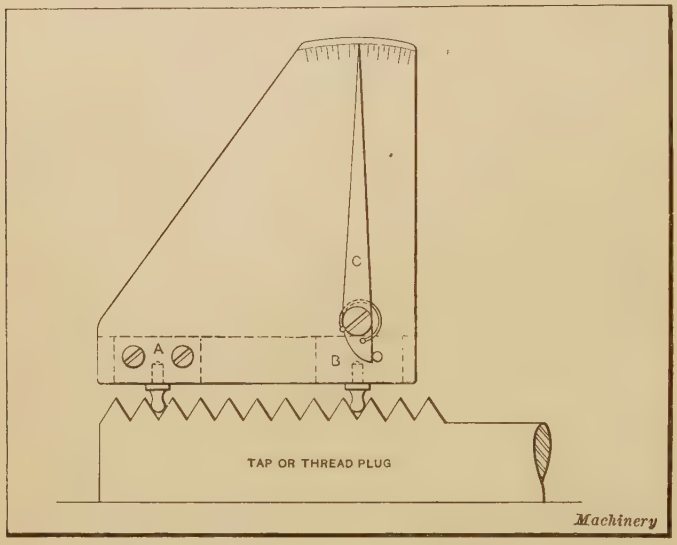


Fig. 16. Simple Device for Testing Lead of Taps and Screws

Simple Device for Testing Lead of Screw Threads. — Fig. 16 shows a simple device which is used as a comparator for testing the lead of taps and screws. It consists of a fixed block *A* and a sliding block *B* held in a frame as illustrated. The blocks are provided with pointers having ball points. The sliding block operates an indicating needle *C* which, on a magnified scale, indicates the error in lead. The manner in which this instrument is used is as follows: The position of the pointer on the scale is noted when the instrument is brought in contact with a standard plug that engages the ball points; the free block *B* adjusts itself to the thread into which its point enters and

carries with it the needle *C*. Next the tap or screw to be tested is placed in position against the device. If the lead of the screw or tap is correct, that is, if it is the same as the standard, the pointer will occupy the same position on the scale as it did when brought in contact with the plug. If the tap or screw is long or short in lead, the pointer will show the amount by its movement either to the right or to the left. The circular arc of the scale is generally graduated to read to 0.001 inch.

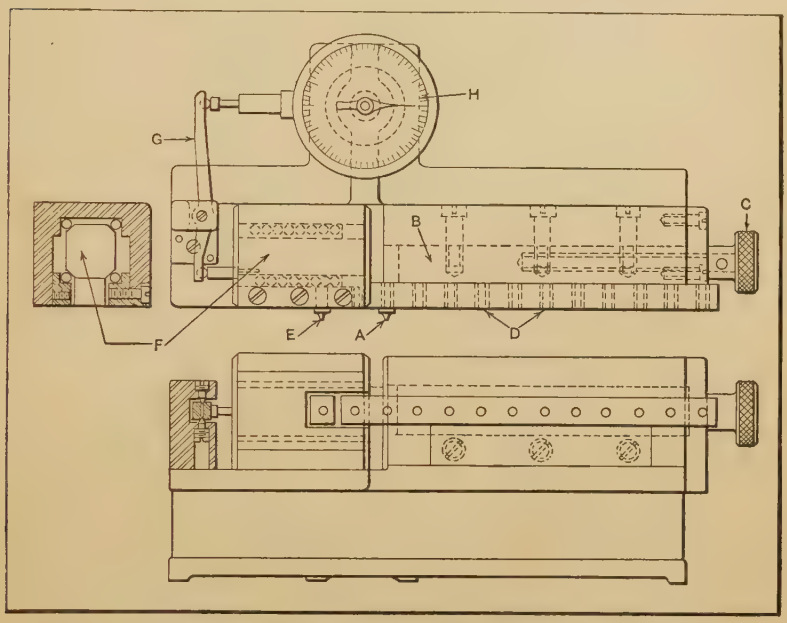


Fig. 17. Indicating Comparator for Testing Lead of Taps and Screws

Indicating Comparator for Testing Lead of Taps and Screws. — A somewhat more elaborate device for testing the error in lead of taps and screws is shown in Fig. 17. In this, one ball point *A* is fixed and is mounted in slide *B*, which is operated by a knurled-head screw *C*. This ball point *A* may be screwed into any of the holes *D* which may be located $\frac{1}{2}$ inch apart. The other ball point *E* is inserted in a movable block *F* mounted on ball bearings. This block is connected, through lever *G*, with

the indicator or sensitive gage *H*, which is so arranged and graduated that each thousandth of an inch can be easily read. When the standard plug is placed against the device, the ball points enter between threads the same as in the device previously described, and slide *B* is adjusted by the knurled-head screw *C* so that the indicator points to zero. When the screw

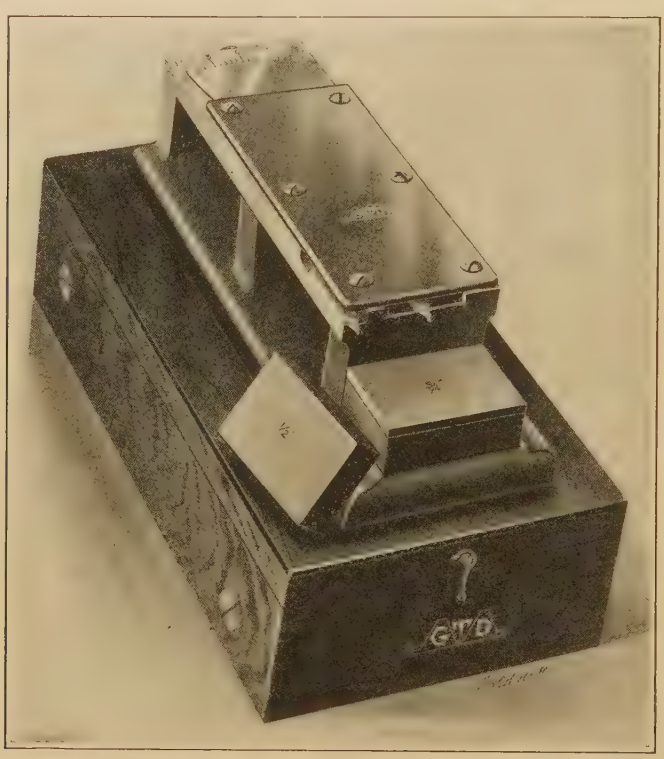


Fig. 18. Wells Bros. Rapid Screw and Tap Lead Tester

or tap to be tested is placed against the ball points, any error will then be apparent by the motion of the needle.

Wells Indicator for Testing Lead of Screws and Taps. — A simple but effective device for testing the lead of screws and taps is shown in Figs. 18 and 19. This device is made by the Greenfield Tap & Die Corporation, Greenfield, Mass., and, as shown in Fig. 18, comprises a base carrying one fixed and one

movable pointer. These pointers are made to enter the threads of the screw, as shown in Fig. 19, the indicator previously having been set to zero by means of a reference plug. In using this device, the screw is simply pressed against the points and any deviation from the correct lead is shown by the indicator in thousandths of an inch. A set of steel blocks furnished with this device permits of the rapid testing of any size of screw. The blocks vary in thickness, thus enabling the screw to be placed at the proper height so that the points will come in the center or on the axis of the screw. The points are removable to enable them to be replaced when worn.

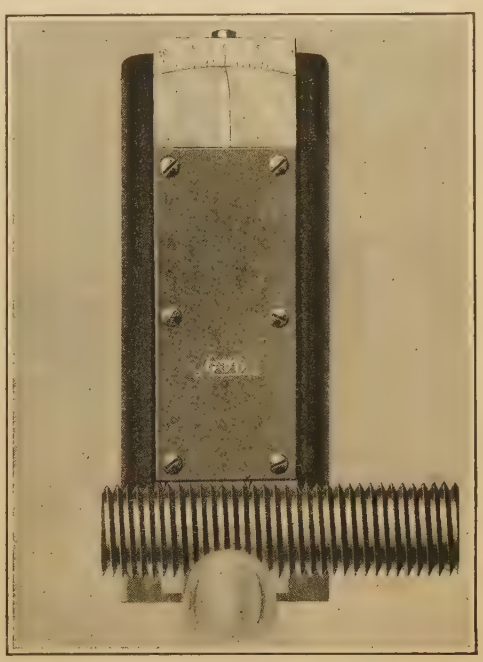


Fig. 19. Indicator shown in Fig. 18 in Use testing Lead of Screw

Wolfe Dial Indicator for Testing Lead of Taps. — A dial indicator known as the Wolfe indicator, which is particularly adapted for testing the lead of taps, is shown in Fig. 20. It can be used for testing any screw or tap having a length of one inch or more, and an accuracy of 0.0002 inch is said to be easily obtained. The dial of the indicator is graduated to read to thousandths of an inch and has a range of 0.024 inch on each side of the zero mark. This instrument has two ball points *A* and *B*, which are brought into contact with the thread to be tested; point *A* is movable and point *B* stationary. Point *B* can be unscrewed from its socket and screwed into the socket *K* when a testing range of one inch is desired.

Point *B* is held in a sleeve *C* that can be adjusted by screw *D*, the sleeve being held in position by clamping screw *E*. The loop or handle *G* is used for holding the indicator. In addition to the indicator proper, a centering gage provides a means for enabling taps, screws, etc., to be tested on the center line, thereby insuring the required accuracy. This centering gage can be used on taper as well as straight taps and has a capacity for diameters ranging from $\frac{1}{4}$ to $1\frac{1}{2}$ inch. The adjustable points on the centering gage are graduated in thirty-

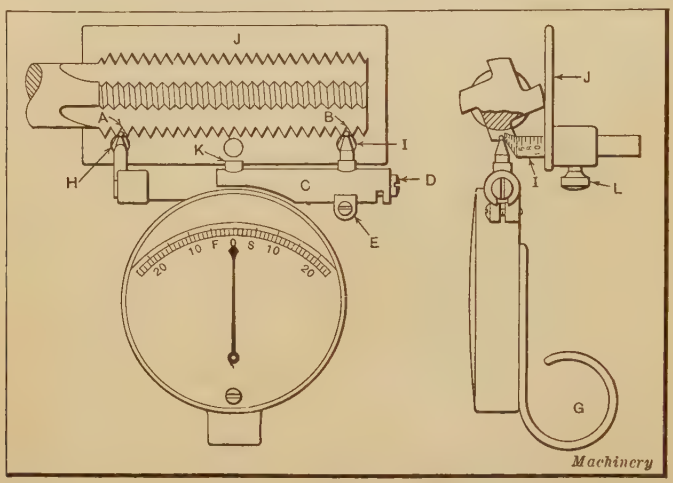


Fig. 20. Wolfe Indicator particularly adapted for Testing Lead of Taps

seconds of an inch, and they may be held in position by thumb-screws *L*.

As the illustration shows, this centering gage also has a main plate *J* against which the piece being tested is held. When using the centering gage, the graduated points are set out from the plate *J* a distance equal to the radius of the tap or screw to be tested. Thumb-screws *L* are then tightened, thus holding the points in the adjusted position. The tap or screw is next placed in the centering gage and is held down on plate *J* and against the points. The indicator is held in the hand with the second finger through the loop *G*. The gage is brought up so

that the stationary ball point *B* enters the thread and rests on the flat end of point *I*. The movable point *A* enters the thread and rests on the flat part of the point *H*. The indicator will then show whether the thread is " long " or " short " in thousandths of an inch. If the thread is accurate, the needle will remain at zero. If it is " long," the pointer will move in the direction of *F*; and if " short," it will move in the opposite direction.

Lead Test Indicator. — Figs. 21 and 22 show a thread test indicator used in the Pennsylvania Railroad shops for testing staybolts, taps, and leadscrews. This instrument comprises a standard on which is pivoted a sensitive spring pointer *H* and a stationary pointer *J*. The latter is mounted on a bar *K* which may be adjusted minutely lengthwise by screw *L*. The indications of pointer *H* are read on segment *M*, the support of which may be adjusted, through the circular dovetail slot, about the center of the pivot of *H* to bring the reading to zero. This adjustment is effected by the screw *N* and clamped by screw *O*. Spring stop-screws *P* limit the extreme movement of the needle. When in use, the points are adjusted to span a certain number of threads and the instrument is pushed against the screw to be measured until the measuring points are firmly pressed into the thread. Scale *M* is then adjusted until the indicator points to zero. The instrument is then moved from one place to another along the thread and, if the needle points to zero in all positions, the thread is uniform.

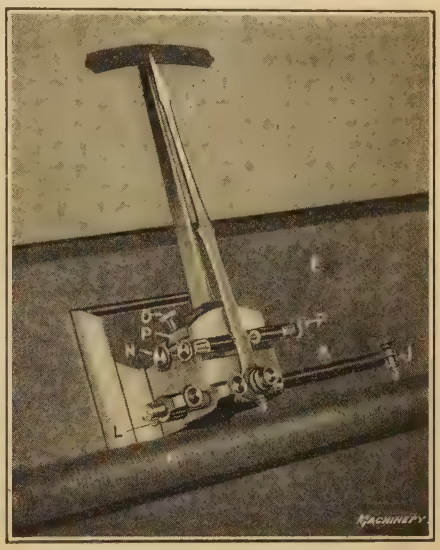


Fig. 21. Lead Test Indicator having Wide Application

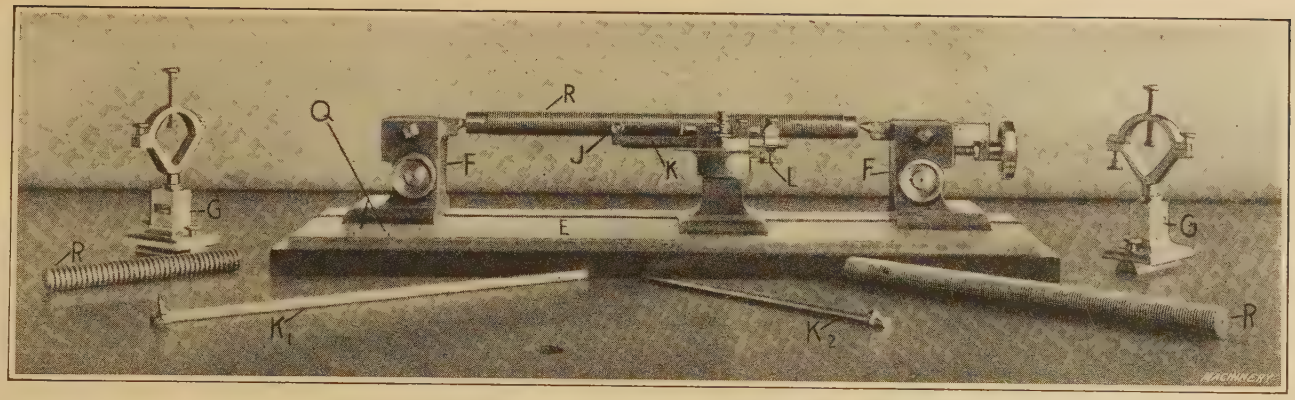


Fig. 22. Lead Test Indicator

Another use of this tool is in finding the amount by which the threads are longer or shorter than the true pitch. By this test, the indicator is first set to zero on a reference screw of known accuracy; the screw to be tested is then put in place and measurements are taken at various points along its length. The readings on the dial show whether the pitch is long, short, or regular. The indicator can also be used for measuring the size of thread at or near the pitch line. The indicating points are balls, and various sizes are provided to suit the different pitches and shapes of threads. An extra set is shown at Q in Fig. 22. Various model screws for comparative measurements are also shown at R, and bars of various lengths for carrying the fixed indicating points are shown at K_1 and K_2. The whole arrangement makes the instrument practically universal in application, since baseplates

of any length may be used and the centers or yokes fastened to them at the points required.

Bicknell-Thomas Thread Lead Indicator. — The tool shown in Figs. 23 and 24 is a simple device for testing the lead of both external and internal screw threads. When in use, the tool is held in one hand, preferably the left, and the screw is pressed against the two points, which are spaced $\frac{1}{4}$, $\frac{1}{2}$, or 1 inch apart, as desired. If the lead of the thread is normal, the indicator

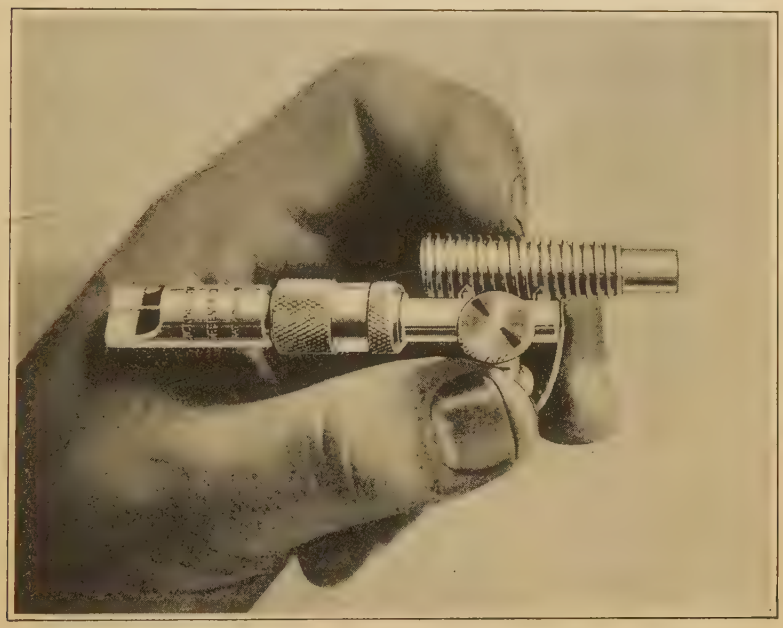


Fig. 23. Thread Lead Indicator in Use testing an External Thread

needle will register zero; if the lead is short, the needle will show on the minus side; if long, on the plus side. Each line of the graduation represents 0.001 inch. The " table " on which the screw rests in testing is adjustable to accommodate screws of any diameter. For internal measuring, the table is removed by loosening the thumb-screw and drawing it off. The end of the instrument containing the point is small enough so that tapped holes as small as $\frac{1}{2}$ inch in diameter can be tested. This

is a feature which is of the utmost importance in making sure that the lead of the threads on both the screw and in the tapped hole are the same. A master is furnished with each gage so that the operator may be sure at all times that the needle point is at zero when the gaging points are spaced correctly.

Testing Angle of Thread. — Fig. 25 shows a simple device for testing the angle of a thread. This consists of a special base carrying two center supports, and a rear support or slide for holding cone-pointed inspection rods.

The procedure followed in using this device is to place the plug to be inspected on the centers, and then locate one of the

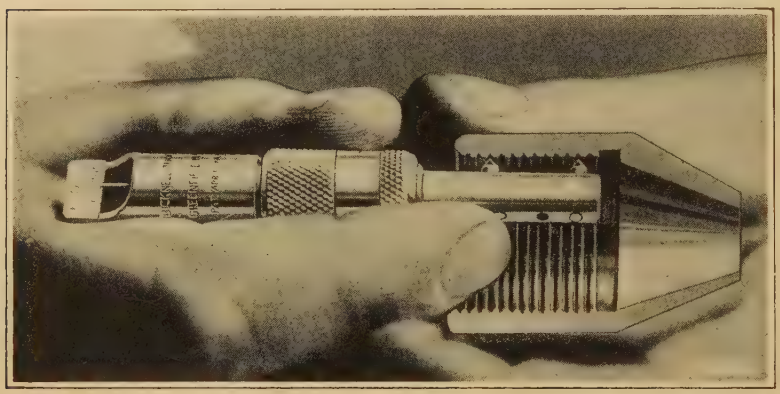


Fig. 24. Thread Lead Indicator in Use testing an Internal Thread

cone-pointed rods with the carefully ground and lapped point in the space between the threads. A sheet of white paper, for illuminating purposes, is then placed on the base, as shown, and the thread viewed through the magnifying glass. If it is desired to determine just how much the angle is off, rods having points ground to included angles of $60\frac{1}{2}$ or $59\frac{1}{2}$ degrees are used, the angle depending upon the pitch of the thread and the tolerances permitted. Usually, however, the thread is tested for "light," and if the cone point does not bear evenly on the angular sides, the thread is not passed. By using the two points, which are spaced exactly 1 inch apart, it is also possible to test the lead with this device.

Limit Working and Inspection Thread Gages. — Most of the devices described in the foregoing are somewhat limited in their application and will not be found suitable when a large number of threaded parts are to be produced within certain limits of tolerances. As a general rule, manufacturing gages are designed to handle one diameter and pitch of thread. The most common form of limit thread gage is shown in Fig. 26. For threaded

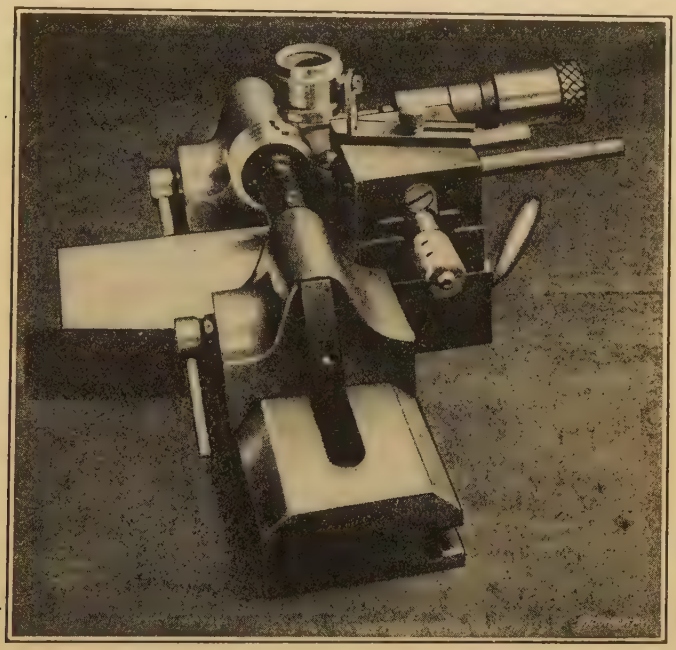


Fig. 25. Device for Inspecting Angle of Thread

holes, a limit plug gage *A* having two threaded ends, one of which is made to enter the hole and the other not to enter (when the work is satisfactory) is used. For external threads, such as screws, etc., a templet, as shown at *B*, having " go " and " not go " holes is used; or, for the larger sizes, two rings, as shown at *C*, may be employed. The chief objection to these gages is that they do not indicate what element of the thread is in error. For many classes of work, however, they fill all requirements, especially when the necessary care is exercised in producing the

tools used in cutting the threads. The general practice is to use the double-end templet *B* for sizes up to one inch in diameter; the " go " end is knurled. For sizes over one inch, two rings, as

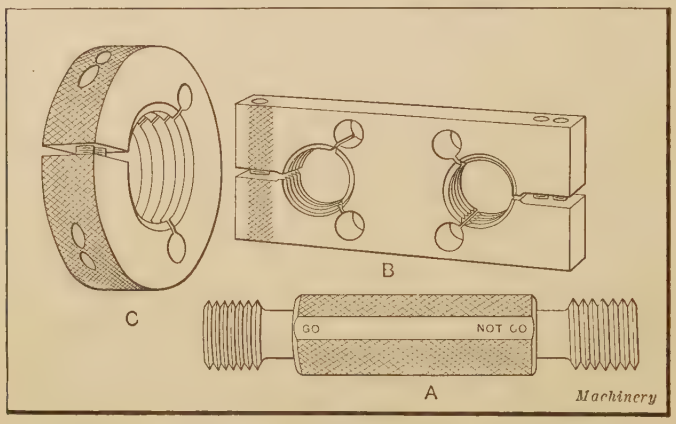


Fig. 26. Limit Working and Inspection Plug and Templet Screw Gages

shown at *C*, are used. These gages are adjusted to the plug *A*. For inspecting the U. S. standard thread, the threads in the ring and plug have flat tops — one-eighth the pitch — and sharp

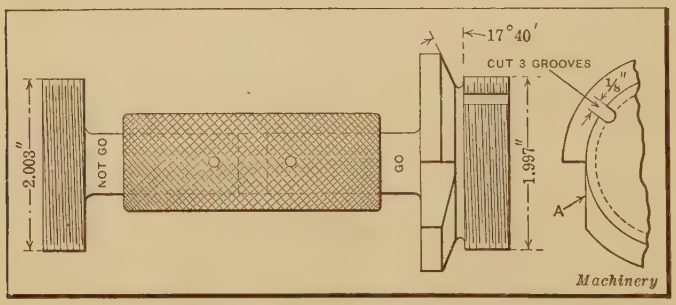


Fig. 27. Double-end Limit Plug Gage having Beveled Shoulder for Inspecting Chamfered Thread Hole

V-bottoms to clear fine chips, dust, and dirt, and also to insure a bearing upon the angular sides of the thread.

In cases where the threaded bushings, sockets, etc., are made with a chamfered mouth, the " go " end of the plug gage, as

shown in Fig. 27, is made with an enlarged shoulder, the front face of which is beveled to the angle required. This shoulder is then cut away, as shown at *A*, to provide a means for inspecting the accuracy of the angle. The threaded part has three grooves to collect fine chips and dirt.

Limit Snap and Plug Gages for Threaded Work. — A limit snap gage for threaded work, which is manufactured by the Greenfield Tap & Die Corporation, is shown at *A* in Fig. 28. This gage is used for testing the pitch diameter of screw threads, and is provided with hardened cone points, carefully

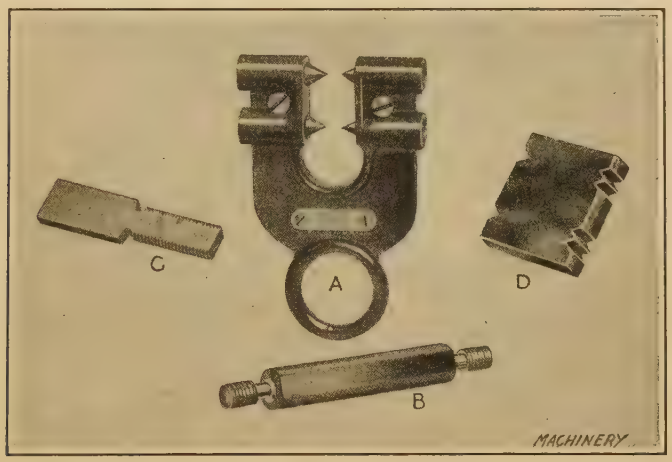


Fig. 28. Limit Snap Gage and Setting Plugs

ground to the angle of the thread wall. The points are not placed directly opposite each other, but are offset an amount equal to one-half the pitch. The cone points are adjustable and are set by locking screws, which are sealed by the inspector after he has checked the gage; *B* shows a setting plug that is similar to the plug shown at *A* in Fig. 26, and is used for sizes up to $\frac{1}{4}$ inch; *C* is used as a setting plug for sizes from $\frac{1}{4}$ up to 3 inches; and *D* for sizes from 3 inches up.

Fig. 29 shows the snap gage illustrated at *A* in Fig. 28, held in a stand and used for the rapid inspection of screw threads. This illustration shows clearly the application of this gage.

At *A*, the screw being tested is too small and has passed both sets of points; at *B*, the screw is too large and will not pass the upper or "go" points; while at *C*, the screw is just right, as it has passed the upper points and is hanging on the lower ones.

Limit Snap Gages for Testing Lead and Pitch Diameter. — While the cone points in the gage shown at *A* in Fig. 28 are set off an amount equal to one-half the pitch, they do not cover a sufficient number of threads to detect errors in lead. A modification of this gage is shown in Fig. 30. This is pro-

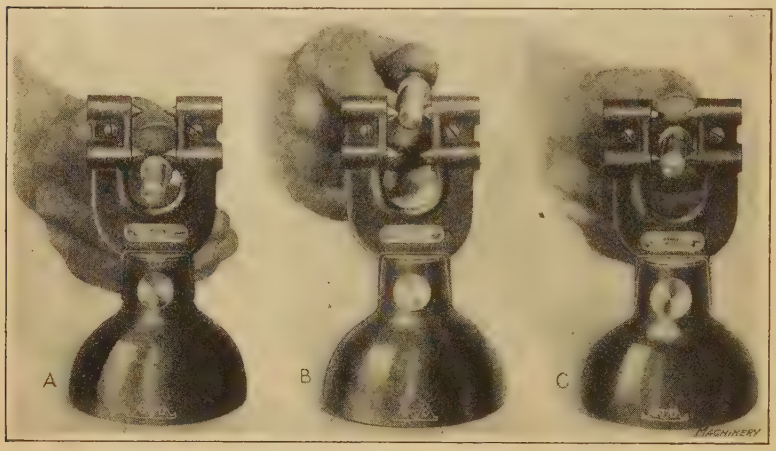


Fig. 29. Snap Gage shown in Fig. 28 used for Inspecting Screw Threads

vided with two sets of three points, making six cone points in all. The points held in the lower jaw of the gage are spaced approximately $\frac{1}{2}$ inch apart, depending upon the pitch of the thread, and the upper points are offset an amount equal to one-half the pitch. By the use of this gage it is possible to detect errors in lead which would prevent the screw and nut from fitting together as they should.

Another gage of the snap type, which inspects both the lead and the pitch diameter of a screw thread is shown in Fig. 31. This gage comprises a frame carrying three conical points *B*, *C*, and *E*, which are accurately ground to the required angle;

the extreme ends of the points are removed so that the points will come in contact with the sides of the thread. Points *B* and *C* are fixed in the lower jaw of the gage, so that their

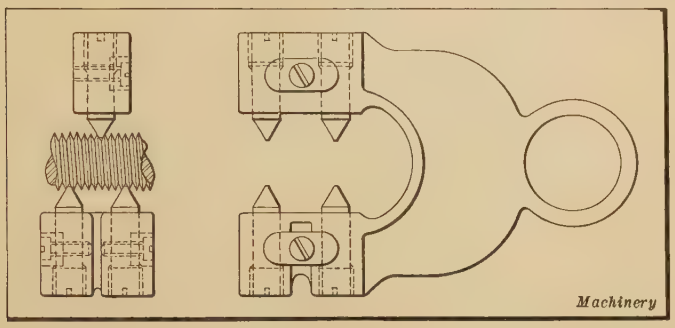


Fig. 30. Limit Snap Gage for Testing Lead and Pitch Diameter

center distance is equal to the distance between a number of threads representing twice the length of a nut of corresponding diameter. The third point *E* is held in the upper jaw and is midway between the lower points. All three are set

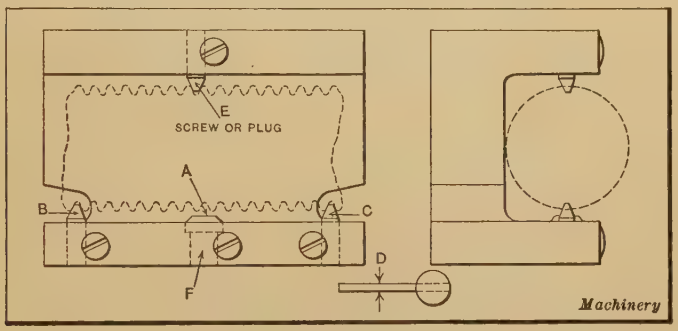


Fig. 31. Another Limit Snap Gage for Testing Lead and Pitch Diameter

to a known standard. Located opposite the point *E* is a point *F* having a flat face *A*, which is adjusted so that the small cylinder *D* (which is of such diameter that it will touch the sides of the thread halfway down its depth) will just enter the thread of the screw when made to the minimum pitch

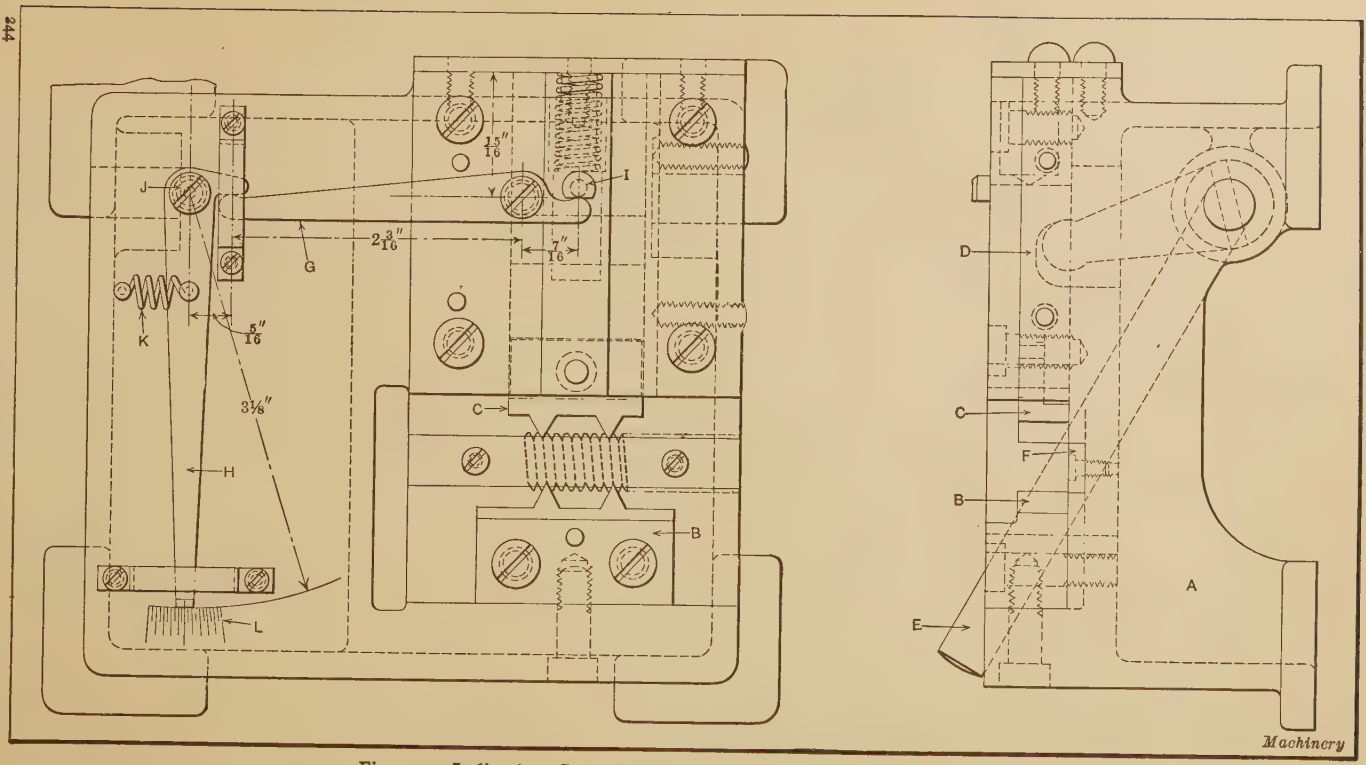


Fig. 32. Indicating Gage for Inspecting Lead and Pitch Diameter

diameter. In testing, if the screw enters between the points, and the "not go" plug *D* does not, the screw is within the required limits for pitch diameter; any error in pitch is compensated for by the necessary reduction in pitch diameter.

Indicating Gage for Inspecting Lead and Pitch Diameter. — When the volume of work to be inspected warrants the additional expense, an indicating gage is to be preferred to one of the rigid snap type. A satisfactory indicating gage for testing the lead and pitch diameter of screws is shown in Fig. 32. This gage comprises a cast-iron base *A* to which is attached

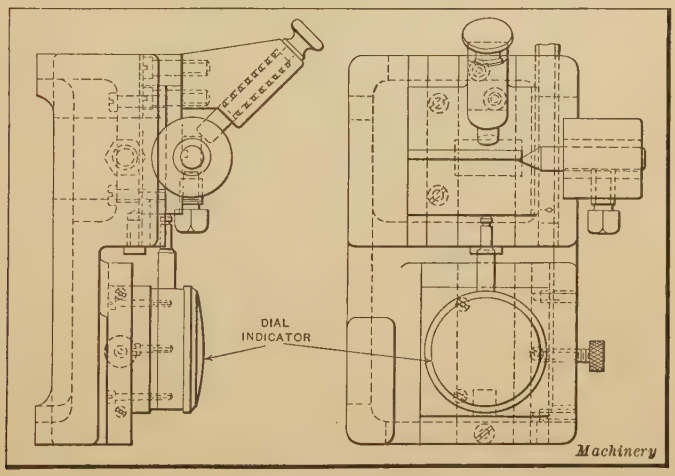


Fig. 33. Fixture for Testing Lead of Opening Die Chasers

a fixed jaw *B*; the movable jaw *C* is attached to a slide *D*. Jaws *B* and *C* are each provided with two carefully ground and lapped V-projections, which fit in the threads of the screw being tested. The extreme ends of the points are removed, so that the projections will come in contact with the sides of the threads. The projections on blocks *B* and *C* are located exactly 1 inch apart and one set of points is offset from the other an amount equal to one-half the pitch of the thread being inspected. Slide *D* is kept in the forward position by an open-wound spring, and block *C* is withdrawn from contact

with the work by handle *E*. Thus the pressure on the work being tested is that exerted by the spring that holds the slide in the forward position. When being inspected, the work is placed on the hardened and ground block *F*. The indicating mechanism comprises two levers *G* and *H*. The short end of lever *G* comes in contact with the flattened face of a plug *I* on slide *D*. Lever *H* is fulcrumed at point *J* and is kept in contact with the long arm of lever *G* by a spring *K*. The ratio of the two levers, or the multiplication of the error, is 50 to 1, so that the marks on scale *L* (which are spaced 0.050 inch apart) represent an error in the diameter of the work of 0.001 inch. With this device, it is easy, therefore, to detect errors as fine as 0.00025 inch, although for the average run of work this degree of refinement is considered unnecessary.

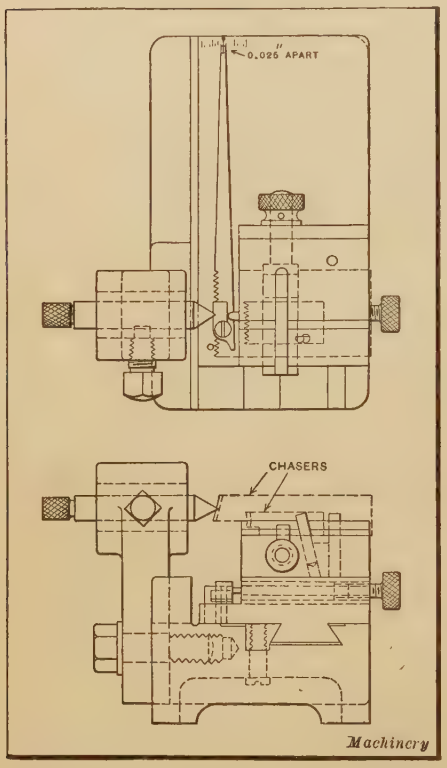


Fig. 34. Fixture for Testing Straightness of Opening Die Chasers

Inspecting Die Chasers. — The extensive use of opening die-heads for the production, in large quantities, of commercially accurate screws has necessitated, in many plants, the use of fixtures for inspecting the chasers, in order to insure that the pitch is within the desired degree of tolerance; also, in straight chasers, that the threaded face is correct in relation to the rear face. One simple but effective device for testing the lead of die chasers is shown in Fig. 33. This fixture was

designed for testing the lead and registration of Geometric and Modern die chasers. It consists of a base carrying several slides that give the required movement, and an indicator for testing the chaser. A chart is prepared for checking the registration of the starting teeth on the chaser.

The chaser is located by the same slot that locates it in the die-head and, as shown in the illustration, is held in place by a spring plunger pressing upon it an at angle of 45 degrees. The top slide is located by a pointer which is held on a bracket and meshes with one tooth of the chaser. The spindle of the dial indicator bears against the end of this slide. To test

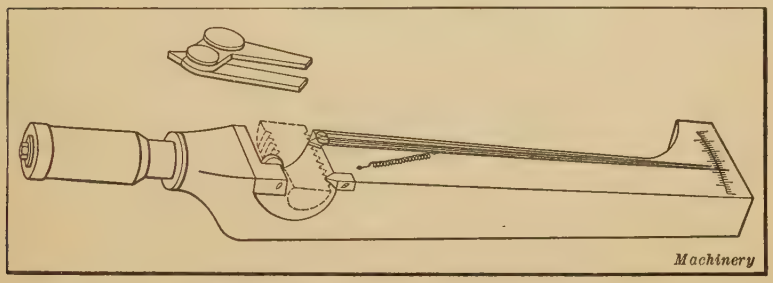


Fig. 35. Gage for Measuring Variations in Diameter and Lead of Screws and Taps

the chasers, No. 1 is set at zero on the dial indicator, and then the chart is used to determine if the other chasers are correct in relation to the first by noting the position of the needle on the indicator as each chaser is put in place.

Fig. 34 shows a fixture for testing the straightness of Geometric and Modern die chasers. In this case, the chaser is also mounted on a slide, and a pointer, in connection with a multiplying lever, is used to indicate the distance from the rear face or slot to the pitch line of the chasers. The slide is adjusted to bring each tooth successively in line with the pointer, and then the movement of the indicating lever is noted. This lever is kept in contact with the slide so that any change in the position of the slide for the various teeth in the chaser is multiplied by the indicator. The lower slide is adjusted to

bring the pointer in line with the various teeth of the chaser while they are being tested.

A. S. M. E. Gaging Devices. — In Figs. 35 to 42, inclusive, are shown the gaging devices considered by the sub-committee on gaging systems of the American Society of Mechanical Engineers, in its effort to find a gage that will quickly measure variations in both lead and diameter. The devices shown in Figs. 35, 36, and 39 are suitable for a wide range of diameters and pitches; the other gages are limited to one size of screw or tap.

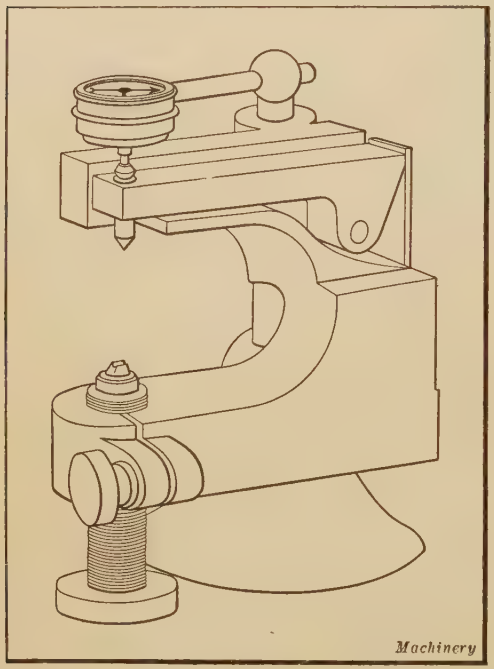


Fig. 36. Gage for Measuring Variation in Pitch Diameter

The gage shown in Fig. 35 measures the variation from standard of both the pitch diameter and the lead of screws and taps. It is constructed with the fixed V-point, a micrometer adjusted grooved roll, and a floating point. The grooved roll fits over the thread and is free to move sideways to allow for variation in lead. The roll is set to the standard pitch diameter of the work to be tested by the micrometer thimble. A floating point is so connected that the longer lever shows variations in lead, and the shorter, variations in pitch diameter. The work is placed between the points, as shown in dotted lines, and the variations from standard pitch diameter and lead are read directly in thousandths of an inch.

The gages shown in Figs. 36 and 37 are to be used together.

That shown in Fig. 36 measures variations in pitch diameter only. The V-shaped anvil is adjustable through a wide range

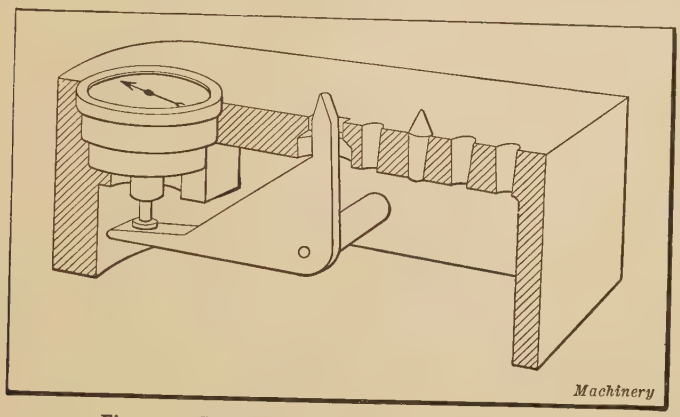


Fig. 37. Gage for Measuring Variation in Lead

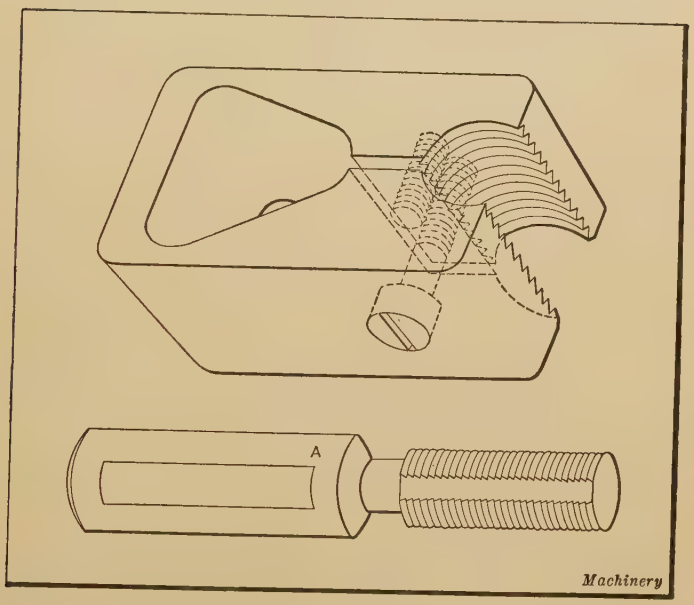


Fig. 38. Split Gage for Measuring Pitch Diameters

of diameters and can be locked in position by a clamping screw. The gaging arm is pivoted, and the gaging point is held in contact with the work at a constant pressure by a

spring at the rear. A dial indicator is in contact with the arm. The gage is set to a standard, and as the work is passed between the points, variations in diameter are transmitted through

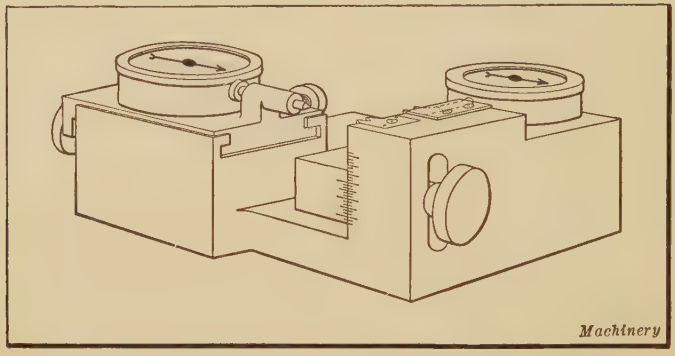


Fig. 39. Combination Gage for Measuring Pitch Diameter and Lead

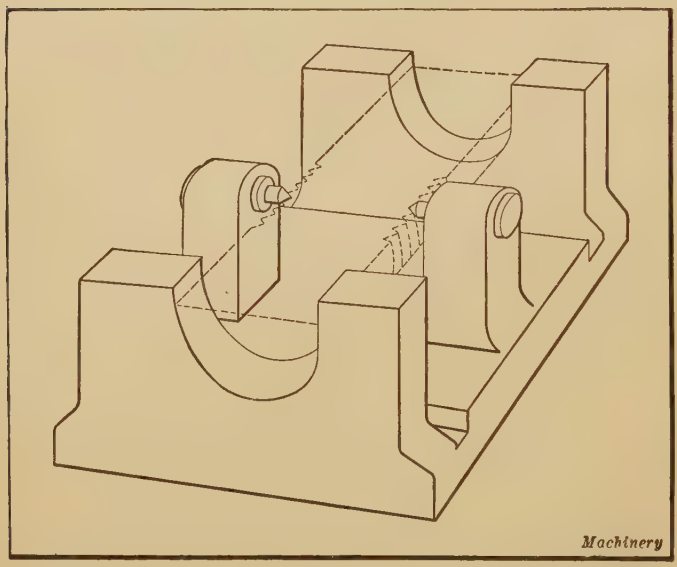


Fig. 40. Gage having Two Fixed Points

the arm to the dial indicator, where the amount of variation may be read directly in thousandths of an inch.

The gage shown in Fig. 37 is for testing the lead only. The

positive point may be used in any of four positions to allow for different lengths of thread. The floating point is part of the bellcrank lever, which is mounted to act on the dial indicator as the distance between the measuring points varies. After the indicator is set to a standard, the work is positioned on the two points. Any variation from the standard in the lead may be read directly, in thousandths of an inch, on the dial.

In Fig. 38 is shown a gage that can be used for pitch diameters only. It is made slightly tapering and is split and fur-

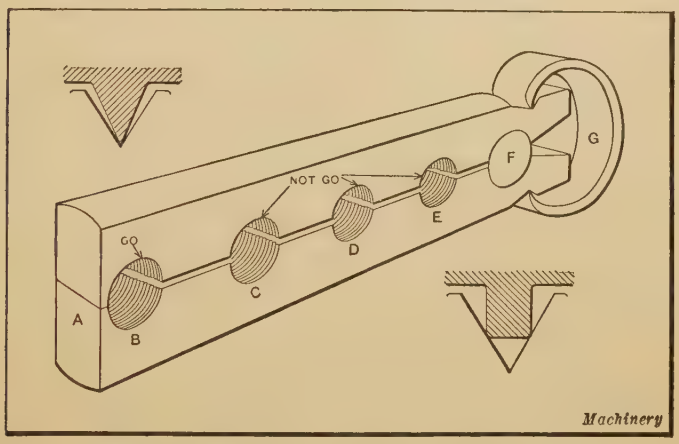


Fig. 41. Combination Gage with Hinged Joint

nished with screws for adjusting and locking. It is adjusted so that the setting standard *A* will screw into the gage until a line on the standard matches a line on the gage. The other lines on the gage indicate 0.001 inch variation from the standard in pitch diameter.

A combination gage for pitch diameter and lead is shown in Fig. 39. In this gage there is a fixed point, and two adjustable points, one for variations in pitch diameter and the other for variations in lead. The errors, in both cases, are read in thousandths of an inch on the dial indicators. The indicators must be set to a standard before testing work. An adjustable

block may be set by a vernier so that work resting on it will have its center line in line with the gaging points.

In Fig. 40 is shown a gage with two fixed points, located correctly. Guiding grooves serve to align the work, which is placed in the gage as shown by the dotted lines. The amount of variation from the standard can only be estimated. A gage fitted with a hinge *F* and spring *G*, like that on a spring caliper, is shown in Fig. 41. The jaws are opened when the screw to be measured is inserted, and are brought together by the fingers. The hole *B* is the "go" gage. It has a standard thread, and, when the flat surfaces between this hole and the end are in contact, any screw that goes in will enter the tapped hole, regardless of the lead error. The other three holes *C*, *D*, and *E* are "not go" gages and test the root diameter, pitch diameter, and outside diameter, respectively. In order to eliminate the question of lead, in both *C* and *D*, only a single turn of thread of special form, as shown by the enlarged views, is used. The last hole *F* is plain, to gage the minimum outside diameter. The "not go" gage *D*, in combination with the "go" gage *B*, limits errors of pitch diameter and lead also.

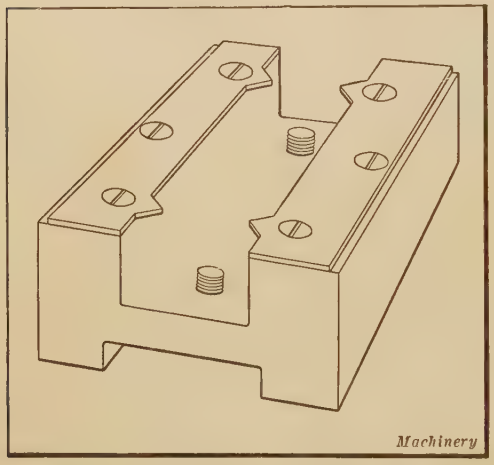


Fig. 42. Combination Gage with Four Fixed Points

The gage shown in Fig. 42 is similar in principle to that shown in Fig. 40. It has four fixed points located in the correct relation to one another. Screws locate the work so that its center line is on the line of the gage points; when the work is placed in position, variations in lead and pitch diameter may be estimated.

Projection Method of Measuring Screw Threads. — A method of inspecting screw threads which, up to the present time, has not been extensively applied, but which for certain purposes (especially laboratory use) can be used with success, is the projection method. This consists chiefly in comparing a screw gage to be tested with a carefully drawn diagram magnified about fifty times. The gage to be tested is mounted on a suitable fixture, and is then illuminated by the aid of a small arc lamp and condenser. Carefully arranged lenses are then used to throw a magnified image of the thread on the chart or screen, and observations are made on the diagram.

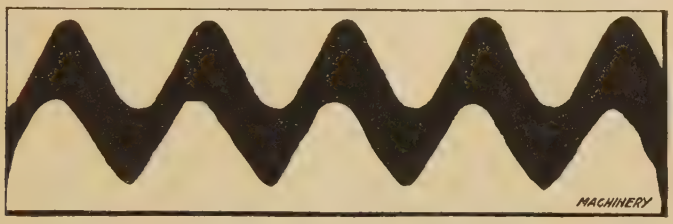


Fig. 43. Comparison of a Screw Thread (Below) and a carefully drawn Screw Thread Outline

The lenses should be chosen to produce a uniform magnification over the entire field, and distortion should be eliminated. As the screen carries a diagram of the thread which is magnified fifty times, it is an easy matter, as shown in Fig. 43, to compare the image projected with the correct thread profile. In Fig. 43, the image has been lowered somewhat to increase the depth of the shadow, and it can be seen that the thread on the gage is comparatively rough and incorrectly formed in places. Another method of comparison is to project, simultaneously, the image of an accurate screw placed beside the one to be examined; the difference between them is easily detected. This method applies to male gages and screws only, as it evidently would be impossible to project the thread in a ring gage or nut in this manner.

CHAPTER VII

GAGING AND INSPECTING GEARS

GEARS are inspected during the process of manufacture to determine if the shape, diameter, width, tooth forms, etc., are correct within the required tolerances, and they are also tested for concentricity. Gears in which the teeth are not concentric with the hole, or are unevenly spaced, are noisy, especially when they are operated at high speeds. The teeth, therefore, receive the most careful attention in the inspection department. The tooth shape, pitch, and pitch diameter are the three most important points to consider.

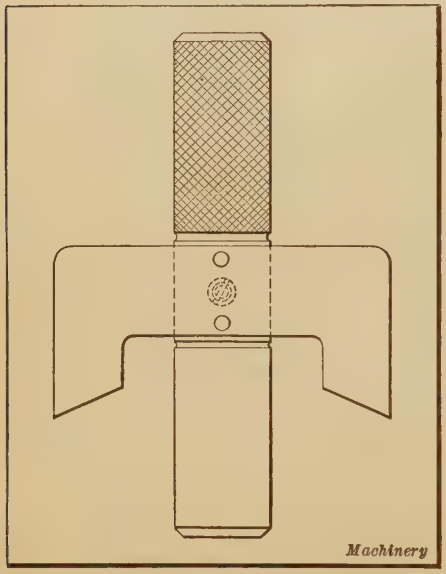


Fig. 1. Combination Plug and Templet Gage for Inspecting Bevel Gear Blanks

Inspecting Gear Blanks. — The methods of testing blanks for spur gears do not differ from those for testing many other interchangeable parts, in which plug gages, snap gages, and regular micrometer calipers are used. For inspecting bevel gear blanks, these tools are employed in connection with properly shaped templets. The type of inspection tool is governed to a large extent by the character and shape of the work. An important point in machining blanks for spur gears is to have the sides finished accurately in relation to the hole, so that the

arbor on which the gears are held, especially when several are mounted together, will not be sprung out of truth. A satisfactory means of testing this is to place the gear blank on an accurate arbor held on centers, and rotate it past the spindle point of a dial test indicator.

Templets for Bevel Gear Blanks. — Bevel gear blanks require some form of templet for testing the relation of the angular faces to the hole and to each other. One form of templet gage for bevel gear blanks is shown in Fig. 1. This gage comprises

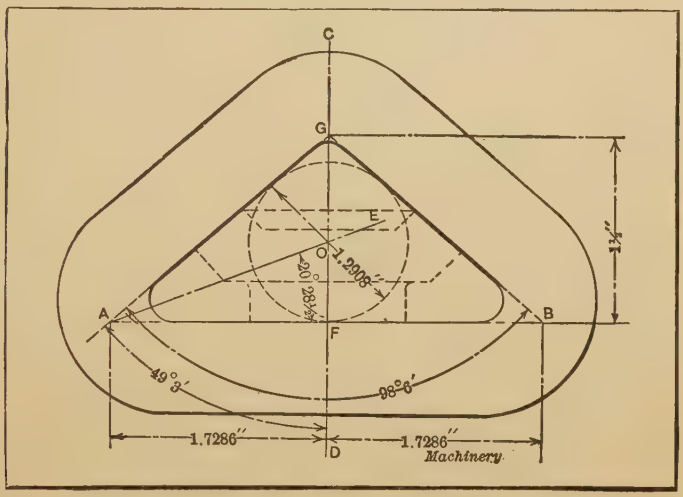


Fig. 2. Templet for Inspecting Miter Gear Blanks

a central plug which fits in the hole in the gear blank, and a templet fitting in a notch cut in the plug. This notch is cut to the center so that the flat gaging face of the templet and the axis of the plug coincide. With this device, it is possible to test the truth of the hole with relation to the angular face of the gear, and at the same time inspect the angle of the face.

A convenient form of bevel gear templet is shown in Fig. 2. This is made of sheet steel, and completely encloses the gear, thus controlling both the angular face and the over-all length. In laying out this form of templet, the first step is to find the center of a circle which will touch all three sides of the isosceles

triangle, as shown by the dotted outline. This is a simple problem in trigonometry, as is shown by the illustration.

Bevel Protractor for Testing Bevel Gear Blanks. — The ordinary bevel protractor familiar to all mechanics is commonly used for testing bevel gear blanks. A special application of this principle is shown in Fig. 3. This device consists of two hinged bases carrying sliding blocks, in which studs are held for supporting the gear blanks being tested. In addition to having regular protractor graduations for setting the gear axes to the required angle, graduations are provided for

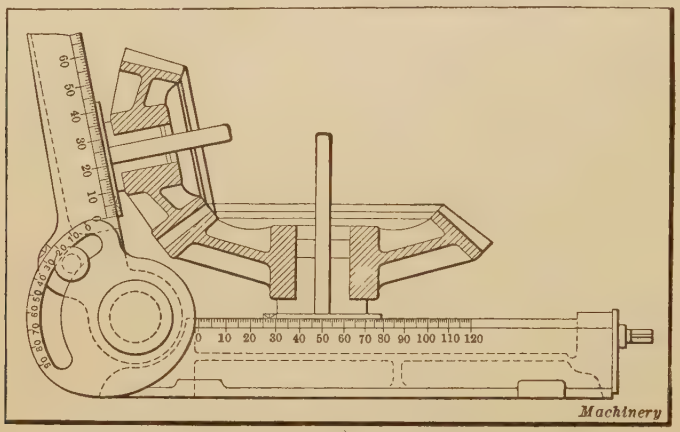


Fig. 3. Protractor for Testing Truth of Bevel Gears

showing the longitudinal settings of the sliding blocks on the two arms. These longitudinal graduations, however, cannot be used to advantage as a measurement of the center distances of bevel gears, but by swinging the movable arm back to an included angle of 180 degrees, the device could be used for spur gears. As the angular face of a bevel or miter gear is of prime importance, two blanks could be held in this fixture and rotated together, to test for concentricity and correctness of angular face.

Gear Tooth Templets. — The simplest form of gear tooth templet is shown at *A* in Fig. 4. This is a piece of sheet steel with a slot in its lower end equal in width to the thickness

of the tooth at the pitch line and of a depth equal to the height of the tooth from the pitch line. The chief objection to this templet is that it wears quickly at the sharp corners *a* and soon becomes inaccurate; *B* shows a form of templet which is used chiefly for bevel gears and is more like a scriber than a templet. It is used to scribe a line on a gear indicating the depth to which the teeth are to be cut at the rear or large end. It is used only when a few gears of one size are to be made.

Gear Tooth Caliper. — The gear tooth caliper shown in Figs. 5 and 6 is a widely used tool in the shop for measuring gear teeth,

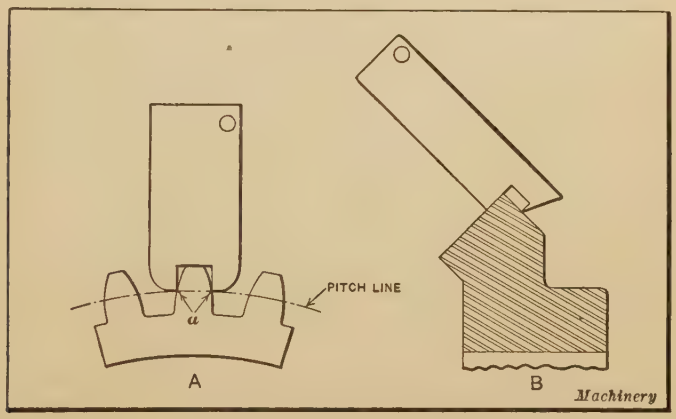


Fig. 4. Templets used in cutting Gear Teeth

especially after cutting the first tooth. This test is especially desirable if there is any doubt about the accuracy of the blank diameter. (The outside diameter of a gear blank can be found by adding 2 to the number of teeth and dividing by the diametral pitch.) To test the tooth thickness, two trial cuts are taken for a short distance at one side of the blank until a full tooth is produced. The vertical scale of the caliper is set so that when it rests on the top of the tooth, as shown in Fig. 6, the lower ends of the caliper jaws will come to the pitch circle. The horizontal scale then shows the chordal thickness of the tooth at this point. When a gear tooth is measured with this caliper, the chordal thickness *T* (see detail of the tooth) is obtained, and not the

thickness along the pitch circle. Hence, when measuring teeth of coarse pitch, especially if the diameter of the gear is small, dimension T should be obtained. It is also necessary to find

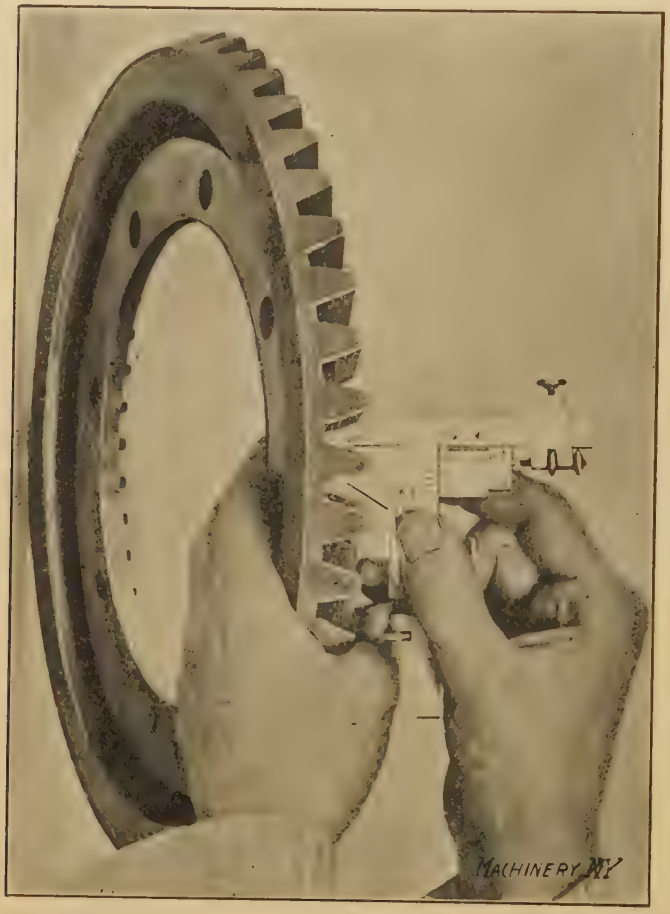


Fig. 5. Brown & Sharpe Gear Tooth Caliper in Use measuring Tooth of Bevel Ring Gear

the height x of the arc and add it to the addendum S to obtain the correct height H, in order to measure the chordal thickness T at the proper point on the sides of the tooth.

If α = one-half the angle subtended from the center of the

gear by one gear tooth (see Fig. 6); N = number of teeth in gear; T = chordal thickness of tooth at pitch line; and R = pitch radius of gear, then:

$$\alpha = 90 \text{ degrees} \div N; \; T = 2R \times \sin \alpha.$$

The height x of the arc equals 1 minus the cosine of angle α multiplied by the pitch radius of the gear, or expressed as a

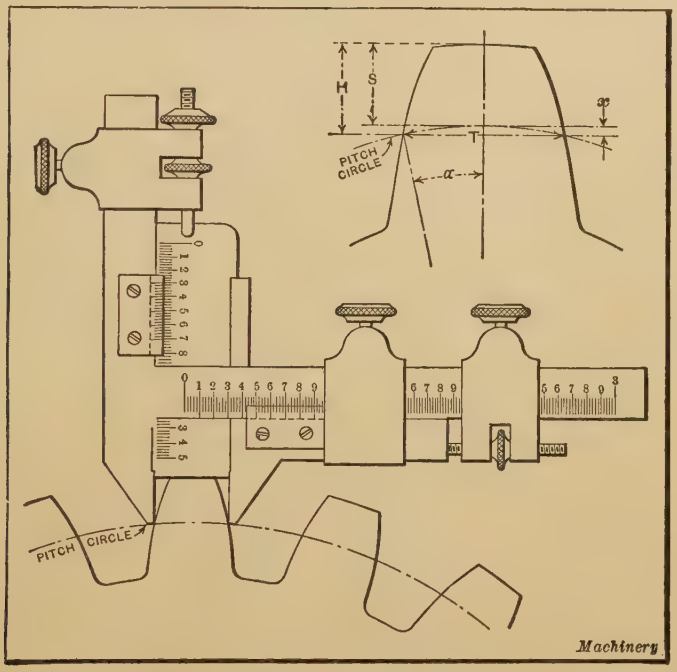


Fig. 6. Diagram illustrating Calculation necessary to determine Thickness of Tooth with Caliper shown in Fig. 5

formula, $x = R\,(1 - \cos \alpha)$. The vertical scale is, therefore, set to the dimension H, or $x +$ addendum S.

Tolerances for Spur Gears. — The three most important factors in a gear are the profile of the teeth, pitch diameter, and center distances. The outside diameter is not so important, as there is always clearance provided at the bottom of the teeth. The limits of accuracy should be based on the pitch, and the

accompanying table gives the limits for gears from 16 to 4 diametral pitch. The tolerance on the shape of the teeth, when they are of the involute form, depends upon several factors. In the first place, if the gears are to transmit a heavy load at comparatively high speeds, and the noise is to be reduced to a minimum, the tooth curves must be as accurate as it is commercially possible to make them. On the other hand, if the gears are to run at slow speeds and noise is not objectionable, much wider limits are permissible. For the average run of good gears, especially for automobile transmissions, an endeavor is made to hold the involute curve to a tolerance of 0.0005 inch. The variation in tooth spacing should not exceed 0.002 inch if the best results are to be expected. Gears having ground teeth, however, are made to closer limits than this for spacing, usually 0.0005 inch.

Manufacturing Limits for Spur Gears

Pitch	Center Distance	Pitch Diameter	Outside Diameter Blanks
16	±0.002	−0.003 to −0.005	0.000 to −0.005
14	±0.003	−0.004 to −0.006	0.000 to −0.005
12	±0.0035	−0.0045 to −0.007	0.000 to −0.006
10	±0.004	−0.005 to −0.008	0.000 to −0.006
8	±0.005	−0.006 to −0.009	0.000 to −0.007
6	±0.006	−0.007 to −0.010	0.000 to −0.008
5	±0.007	−0.008 to −0.011	0.000 to −0.010
4	±0.008	−0.009 to −0.012	0.000 to −0.015

Tolerances for Bevel Gears. — In mounting a bevel pinion which must run in proper mesh with a ring gear, it is essential that backlash be provided for to prevent crowding the teeth. The apex angles of the pinion and ring gear are frequently made to a tolerance as close as 0.005 inch. For gears that are hardened, however, it is necessary, in some cases, to allow a greater tolerance than this to take care of warpage which causes a change of the angle of the bevel gear. When this is done, it is usual to allow for a reasonable amount of backlash between the teeth, the limits varying from 0.005 to 0.007 inch, but never exceeding

0.010 inch. This means that a bevel gear must be straightened before being assembled if the warpage is in excess of the amount given; otherwise, it will be noisy and inefficient.

The tolerances on the teeth of bevel gears are dependent upon the uses to which the gears are to be put. Generally, the tooth curves are made to within 0.002 inch and the spacing of the teeth to the same tolerance. As previously mentioned, however, when a gear is hardened, the tolerance, of necessity, must be greater than this to provide for warpage of the teeth. Bevel gears of the straight-tooth type, when used in automobile trans-

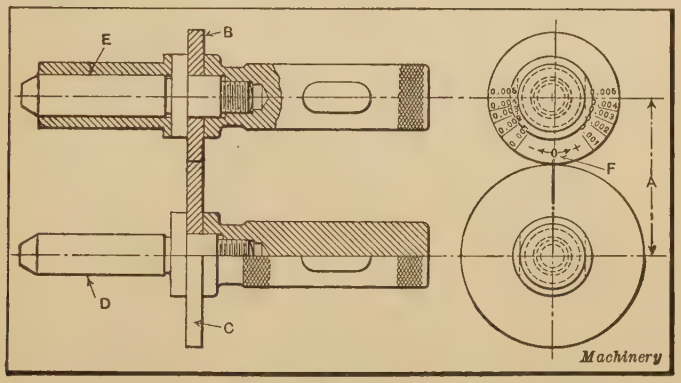


Fig. 7. Special Plug Gage for Gaging Gear Center Distances

missions, are generally run in, using emery and oil to grind down any slight irregularities in the teeth due to warpage in hardening.

Testing Center Distances of Spur Gears. — As mentioned, the center distances of spur gears which must run quietly is an important consideration in the cutting of gear teeth. Fig. 7 shows a simple but effective gage for testing the center distances of spur gears. The gage consists chiefly of two accurately ground collars *B* and *C*, which are held on plug gages *D* and *E*, as shown, the latter being provided with bushings to suit the diameters of the holes in the gears. Collar *B* is ground very slightly eccentric, and the eccentricity is graduated on the collar.

To illustrate the use of this tool, assume that the center distance *A* is 5 inches. The collars *B* and *C* are made so that the

sum of their combined radii will equal this amount. In other words, collar *B* could be 2 inches and *C* 8 inches in diameter. Referring to Fig. 8, which shows the angular spacing for variations in the center distance of the gears, assume that *F* represents the zero or datum line from which the center distances are measured. If the graduated collar *B* is turned through an angle of 36 degrees 51 minutes in a clockwise direction, the center distance will equal +0.001 inch. Similarly, if collar *B* is turned the same amount in a counter-clockwise direction, the center distance

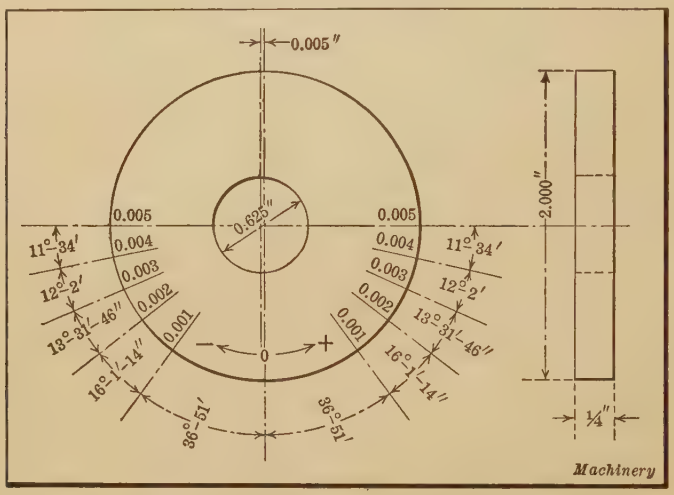


Fig. 8. Enlarged View of Graduated Disk B shown in Fig. 7

will be −0.001 inch. If the collar is rotated through an angle of 90 degrees in either direction, the center distance will be +0.005 or −0.005 inch, depending upon the direction in which the collar is turned. By making a series of plain collars to replace collar *C*, any required center distance may be measured to very accurate limits by using the same graduated eccentric collar *B*.

Testing Pitch Diameter and Concentricity of Spur Gears. — Many interesting fixtures have been devised for testing the pitch diameter, center distance, and concentricity of spur gears. A standard fixture used for this purpose which is built by the Morse Twist Drill & Machine Co. is shown in Fig. 9.

This fixture consists principally of a base carrying one fixed and one movable slide, each slide carrying a stud on which are held the gears to be tested. The gear held on the stud

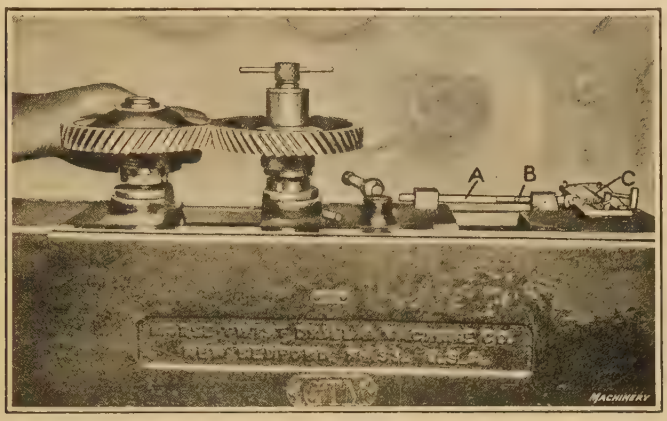


Fig. 9. Standard Fixture for Testing Concentricity and Center Distances of Spur Gears

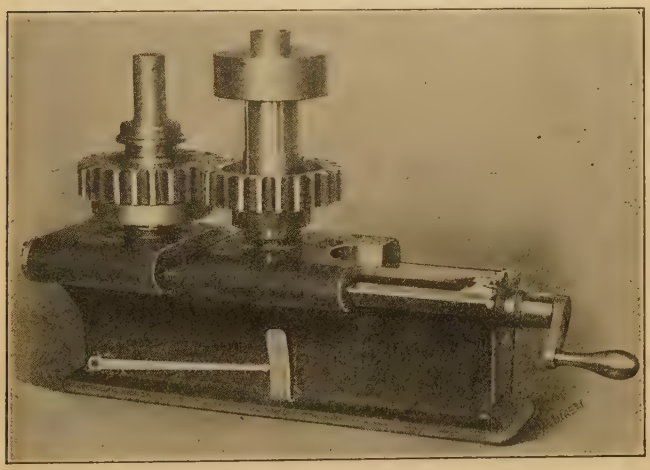


Fig. 10. Fixture for Testing Pitch Diameter and Concentricity of Spur Gears

in the fixed slide is usually a carefully cut, and sometimes ground, master gear, which is brought into mesh with the gear to be tested. The movable slide carries a rod *A*, which makes

contact with a rod *B*, the latter operating an indicating needle *C* through a multiplying lever arrangement. When the center distance as well as the concentricity of the gear is to be tested, the movable slide is set to the required center distance by means of a vernier scale on the bed; then when the gears are rotated, any inaccuracies in either the center distance or concentricity are noted on the scale over which the indicating needle moves. If it is desired to test concentricity only, no attention is paid to the vernier, and the gear to be tested is kept in contact with the master by a spring, not shown, the latter being rotated and the fluctuation of the needle noted.

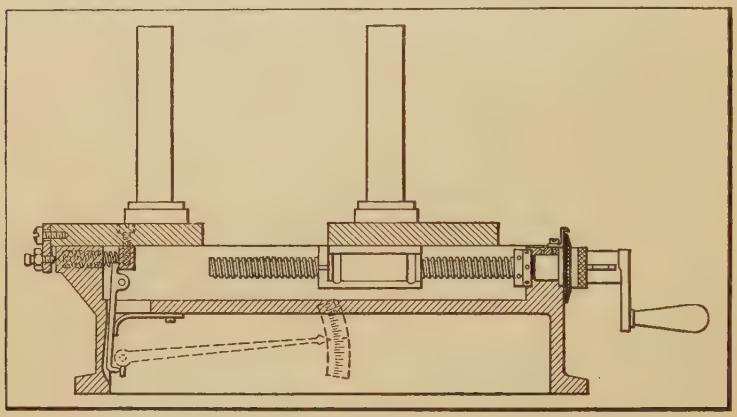


Fig. 11. Sectional View showing Construction of Fixture shown in Fig. 10

Another simple but accurate fixture for testing the pitch diameter and concentricity of spur gears is shown in Figs. 10 and 11. The fixture consists of a cast-iron base upon which two accurately fitting slides are held, each slide being provided with a stud for holding the gears to be tested. The right-hand slide is moved by means of a long adjusting screw, while the left-hand slide has only a limited movement, but transfers its motion greatly magnified to the indicating needle shown. The sectional view, Fig. 11, shows how the motion is transferred to the indicating needle, which measures the difference in concentricity and errors in mesh to 0.0004 inch.

To detect errors in concentricity, it is most convenient to place the gear to be tested on the spindle carried in the left-hand slide, and to use a blank with a single tooth on the other. This single tooth is then meshed in succession with all the teeth of the gear under test, and by observing the different positions of the indicating needle, it is possible to determine errors in eccentricity with great accuracy.

Another spur gear testing fixture differing only in a few minor details from that shown in Fig. 9 is illustrated in Fig. 12. This fixture comprises a base *A* carrying a slide *B* on which a stud is mounted for holding the gear *C* to be tested.

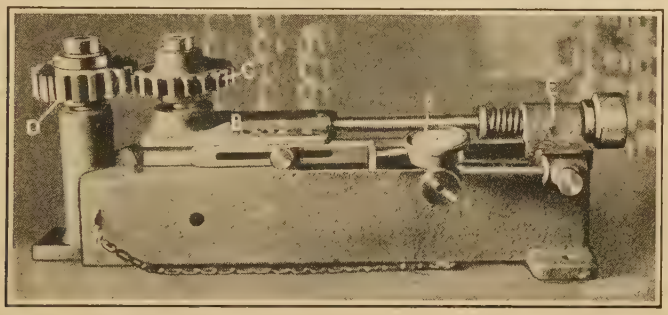


Fig. 12. Fixture for Testing Concentricity of Transmission Gears

The master gear *D* is carefully ground all over, and is held on a fixed stud on a projecting boss of the fixture. Slide *B* is adjusted by a screw to bring the gears into mesh, the screw being a sliding fit in the boss *E* of the fixture. This screw carries a washer as shown, and between the washer and boss *E* is a stiff open-wound spring which serves to keep the gears in mesh with the required tension. The movement of slide *B*, which indicates irregularities in the teeth or lack of concentricity, is read off on the dial test indicator *F*, mounted as shown and operated by a bracket adjustably mounted on the movable slide *B*. Transmission gears for automobiles are generally made with a maximum eccentricity of 0.003 inch.

Power-driven Gear Testing Fixture. — Another gear testing fixture for automobile transmission and timer gears is shown

in Fig. 13. In this case the fixture is power-driven. It consists of a cast-iron plate *A* ribbed at the bottom and machined on the top surface; a cast-iron plate *B* with a projecting arm *C* on which is secured a shoulder stud *D*; a cast-iron segment plate *E* drilled and reamed at one end to fit fulcrum stud *D*, and having at the opposite end a shoulder stud *F* on which revolves a master gear of the same pitch as the gear to be tested; an indicator pointer *G* drilled to pass down over fulcrum stud *D* and axle stud *F*; a graduated brass plate *I* secured

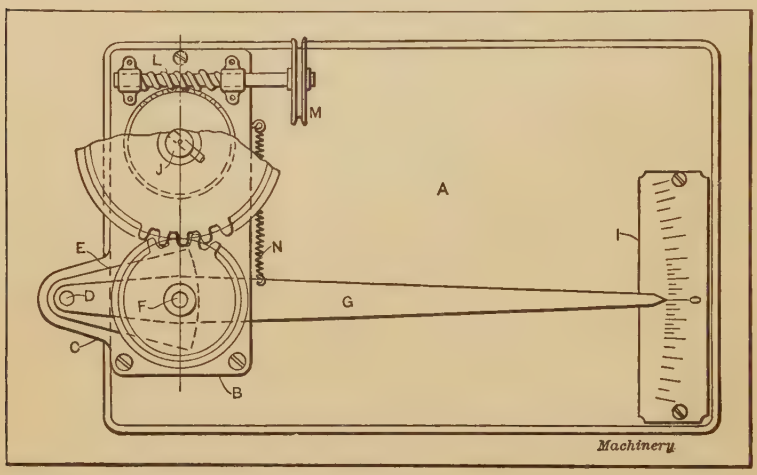


Fig. 13. Fixture for Testing Truth of Cut Gears by revolving with a Master Gear and noting Change in Center to Center Distances

to the base *A*; and a shaft *J*, the lower end of which revolves on a stud beneath the plate *B*. To this shaft is secured a worm-wheel, and on the part which projects above this worm-wheel the gear to be tested is rigidly secured by means of a key.

The worm *L* is made of machine steel, casehardened, and is driven by a $\frac{1}{2}$-inch half-round belt passing over pulley *M*. A steel spring *N* is fastened to plate *B* and index hand *G*. The segment plate *E* is machined on its bottom face, which slides on the upper face of plate *B*. On the upper face of plate *E* rests the index hand, and on top of this is a steel

washer around axle stud *F*. On this washer rests the master gear, which is perfect in every respect. The gear to be tested is revolved by power in the manner indicated, and any irregularity in the diameter is shown on the graduated plate.

Fixture for Testing Transmission Gears. — A gear testing fixture designed especially for testing transmission gears and

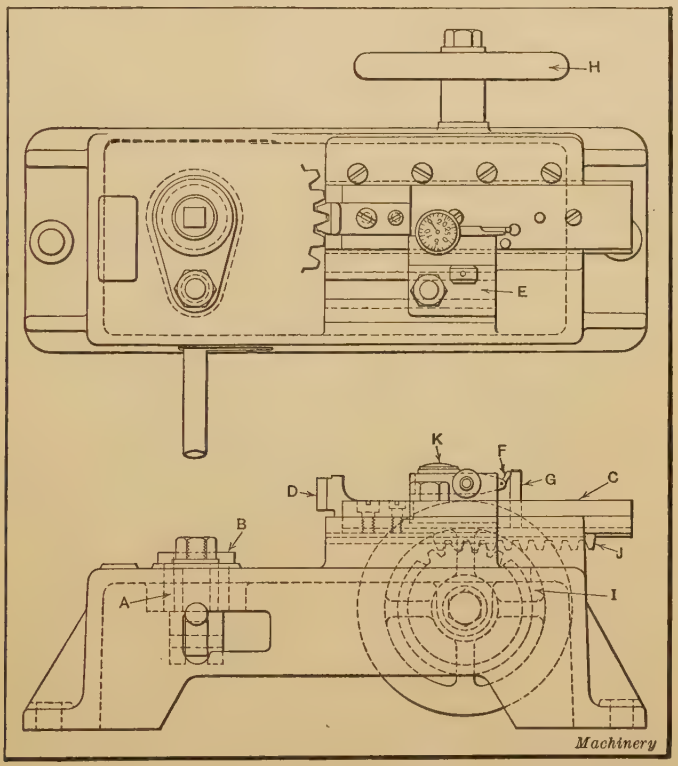


Fig. 14. Fixture for Testing Concentricity and Thickness of Teeth of Transmission Gears

capable of adjustment so that it can handle various sizes is shown in Fig. 14. The gear to be tested is held on a bushing provided with a squared shank, which is inserted in the holder *A*; this holder is provided with a corresponding square hole and held in the fixture by means of plate *B*. An ejecting mechanism comprising a handle, as shown, is provided for

raising the spindle of the arbor out of the bushing when it is desired to remove the latter. The testing device consists primarily of a slide *C* carrying two teeth of a rack *D*. The latter is held to the slide by means of screws, as shown, so that it can be removed and rack teeth of the desired pitch and shape substituted to suit the work to be handled. The testing is done by means of a test indicator which is held on bracket *E*. This indicator is constructed somewhat differently from that ordinarily supplied, the shank being cut off short and the multiplying lever *F* bearing against pin *G*, which is driven into movable slide *C*. A handwheel *H* attached to a shaft which carries a pinion *I* meshing in a rack in the lower surface of the slide is used for adjusting it back and forth to

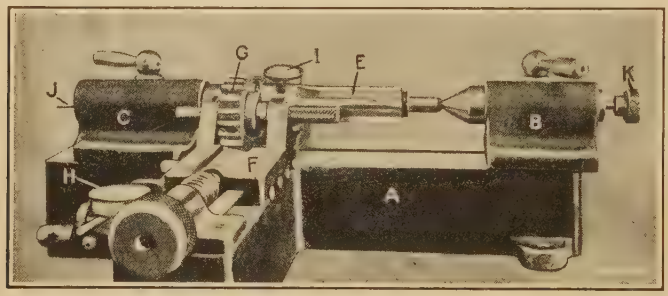


Fig. 15. Fixture for Testing Concentricity of Pinion Shaft

suit the size of gear being tested. When testing the gear, after the latter has been placed on the arbor and the arbor inserted in the hole in the bushing *A*, handwheel *H* is also operated to bring the rack teeth *D* in contact with the gear. The gear is then rotated by hand and the movement of the indicator *K* noticed, and if the gear runs out more than ±0.0015 inch, it is rejected. The indicator is set by means of a ground master gear.

Fixture for Testing Concentricity of Pinion Shafts. — An interesting fixture for testing the concentricity of pinion shafts is shown in Fig. 15. This fixture has a base *A* carrying a tailstock and headstock *B* and *C*, respectively; in tailstock *B* is a rigid center, and in headstock *C*, an indicating center. The

pinion shaft *E* to be tested is mounted on these two centers. Located in a plane at right angles to the slide of the main body of the fixture is a slide *F*, which carries the master gear *G* and a dial indicator *H*. The teeth in the pinion are kept in mesh with the master gear by means of a spring behind slide *F*. A bracket on the rear side of the fixture carries a second dial indicator *I*, the spindle of which is brought in contact with the ground bearing of the pinion shaft. The third indicator projecting from the headstock at *J* and shown in detail in Fig. 16 is of the multiplying lever indicating type. As shown in Fig. 16, this indicator is supported by a sleeve *A*, which is made a

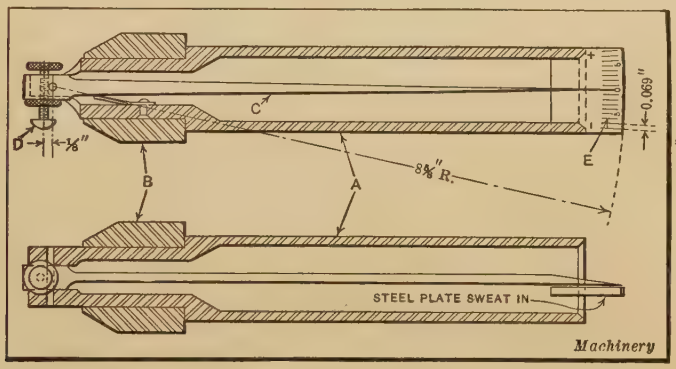


Fig. 16. Details of Multiplying Lever Indicator J, Fig. 15

good fit for the hole in the headstock *C*, Fig. 15. It carries a cone-pointed bushing *B*, which projects from the headstock, the pinion shaft being tested having a hole so that the cone bushing supports it on the opposite end from the rigid center. The cone-center in the hole has been ground by locating the pinion shaft from the bearing at the rear of the pinion. Sleeve *A*, Fig. 16, is slabbed down on the front end and machined to carry the indicating needle *C*. This, as shown, carries an indicator point *D*, which can be adjusted to suit the diameter of the hole in the work and is locked by the nut shown. The rear end of needle *C* is pointed and moves over an index plate *E*, which is provided with graduations spaced 0.069 inch apart. The multiplying lever has a ratio of $\frac{1}{8}$ to $8\frac{5}{8}$ inches, or 69 to 1, so

that each graduation on the scale represents 0.001 inch error in the work. The limits on this part are: Concentricity of pitch circle of teeth, ±0.0015 inch; limits for eccentricity of bearing, ±0.0005 inch; and limits for eccentricity of hole, ±0.0005 inch.

In operation, the pinion *E*, Fig. 15, is located between the centers, screw *K* being adjusted to eliminate end play between the centers. The pinion shaft is then rotated in mesh with the master gear, and the various indicators show the following results: Indicator *H* tests the accuracy of the pitch diameter

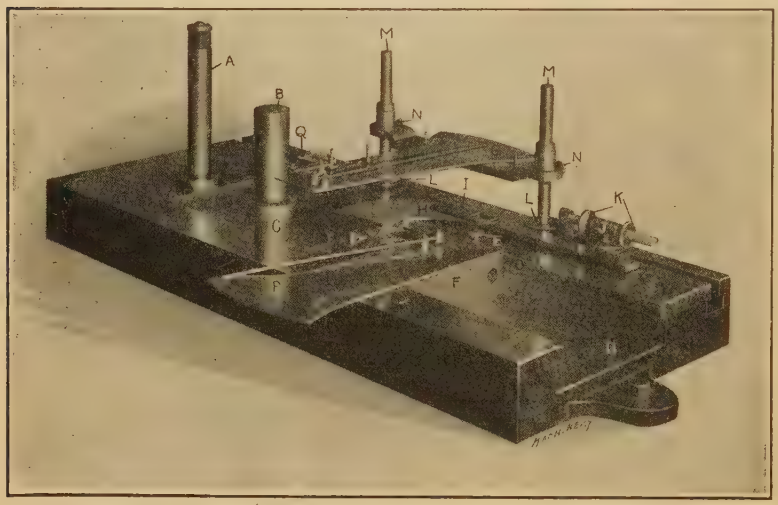


Fig. 17. Device for Testing Pitch Diameter, Concentricity of Bearings, Tooth Thickness at Pitch Line, and Parallelism of Teeth with Axis of Gear

and spacing of the teeth; *I* tests the concentricity of the bearing in relation to the hole; and *J* tests the truth of the hole in relation to the shank bearing diameter. In this way, each important part of the pinion shaft may be tested to accurate limits.

Precision Spur Gear Testing Fixture. — Fig. 17 shows a precision gear testing device for spur gears. It tests the following elements of the gear: Pitch diameter; truth of pitch diameter with hole; thickness of teeth on the pitch line; and parallelism of teeth with axis of gear. In this fixture, revolving stud *A* is

mounted in a fixed position and forms a basis from which the principal dimensions are checked. The removable plug *B*, which is mounted on the sliding block *C* that slides in the ways *D*, is located in relation to stud *A* by the locating pin *E*. Blocks *C* and *F* are connected by two bolts, only one being visible in the illustration. One end of the bolts is screwed into block *C*, while the other end is a free fit in block *F*. The blocks are normally separated by two springs on the bolts, the function of which will be explained later.

The indicating mechanism *G* is located in relation to plug *B* by the vernier *H*. The scale of the vernier is fastened to block *C*, while the vernier is fastened to part *I*, making it integral with the indicating mechanism. The vernier and indicating mechanism are adjusted by nuts *K*. The part *J* is secured in the T-slot by the nut directly below it, and is adjustable along the slot, which extends the full length of the fixture. The indicating mechanism and vernier are locked by nuts *L*; the indicating mechanism is adjusted vertically on the pillars *M* and secured by thumb-screws *N*.

In operation, a master gear is placed on driving stud *A*, and the gear to be tested on plug *B*, being free to revolve on the latter. The locating pin *E* is then inserted in the proper hole along the edge of gib *O*, thus locking block *F* securely and locating the two blocks in the proper relation to each other. The gear is now revolved by the master gear, which is rotated by a handle on the squared end of the stud. The indicator then shows if the teeth are concentric with the hole, and if the pitch diameter is correct. While block *F* is locked to gib *O*, block *C* is free to move within certain limits. This movement is indicated on dial *P* by the multiplying levers. If the gear is out of round, block *C* will slide back and forth against the tension of the springs, thus imparting movement to the indicating lever.

The removable gage *Q*, for measuring the thickness of the teeth, is held against them by spring tension; any variation will then be shown upon the dial by means of the multiplying lever. For testing the parallelism of the teeth and axis, the mechanism is slid up or down along the pillars *M*. The indicating needles

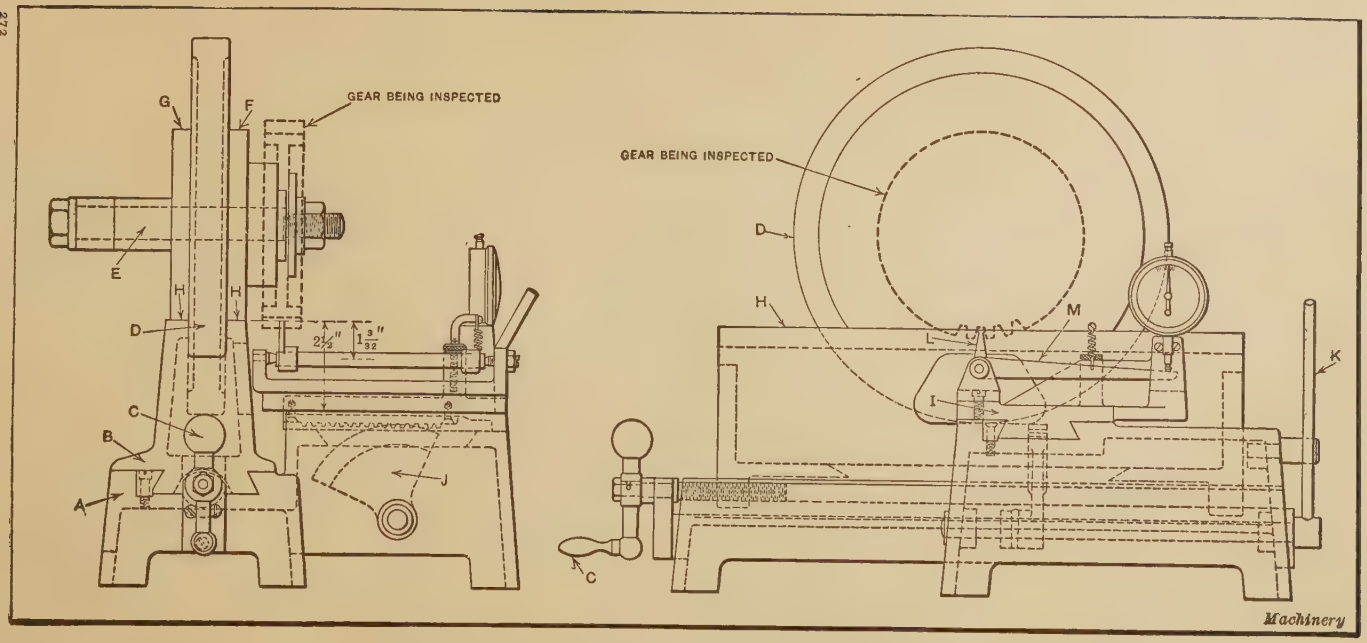


Fig. 18. Fixture for Testing Involute Curve of Spur Gear Teeth

are set at zero by means of a carefully machined and checked master gear, prior to testing the gears.

Fixture for Testing Involute Curve of Spur Gear Teeth. — Many interesting devices have been developed for testing spur gears, especially the shape of the involute curve of the teeth. One method consists in rolling the spur gear in contact with a master and determining whether it is correct or not by the "feel." Another interesting device, which is shown in Fig. 18, determines the shape of the involute curve in such a manner that the amount of error can be read off on an indicator in thousandths of an inch. This device has a base *A* in which a dovetail slide *B* is operated by handle *C*. This slide has a carefully machined slot in its top face in which a disk *D* rotates. Disk *D* is attached to a spindle *E*, which carries the gear to be inspected, and, in addition, two hardened, ground and lapped disks *F* and *G*. These disks run on straightedge *H* and are made equal in diameter to the base circle from which the involute curve on the gear teeth is laid out. Located at right angles to slide *B* is a secondary slide *I* that carries the indicating mechanism. This slide has a rack attached to its lower surface connecting with the segment gear *J* that is operated by handle *K*. For testing the accuracy of the involute curve, the gear, together with the two disks, is rolled along the straightedges and the teeth are brought into contact with the tooth pointer *L* of the multiplying lever *M*. This lever transmits a movement to the needle of the indicator. The multiplying lever has a ratio of 10 to 1 and the indicator is graduated in thousandths of an inch, so that each graduation on the indicator represents 0.0001 inch variation in the shape of the curve. One objection to this device is the shape of the indicator pointer *L*. Instead of being rounded, this should be made to a sharp point so as to trace the involute curve without introducing any error.

Another use of this testing fixture is to determine whether or not the teeth of the gear are in line with the axis. To make this test, the gear and the member to which it is attached are held rigidly on the straightedges. Handle *K* is operated so that slide *I* is moved back and forth, passing the indicator point

across the face of the tooth, and in line with the axis. In this this way the straightness of the tooth surfaces in relation to the axis of the hole in the gear can be accurately tested.

MacCord Odontoscope for Testing Gear Teeth Involute Curve. — Another system for testing the truth of involute curves is by means of the MacCord odontoscope, shown in Fig. 19. By this method it is possible to test the accuracy of the involute curve to a nicety. The fixture has two templets *A* and *B* which are cut out of fairly thick sheet metal and correspond to the teeth of a pair of gears. These templets are secured to arms

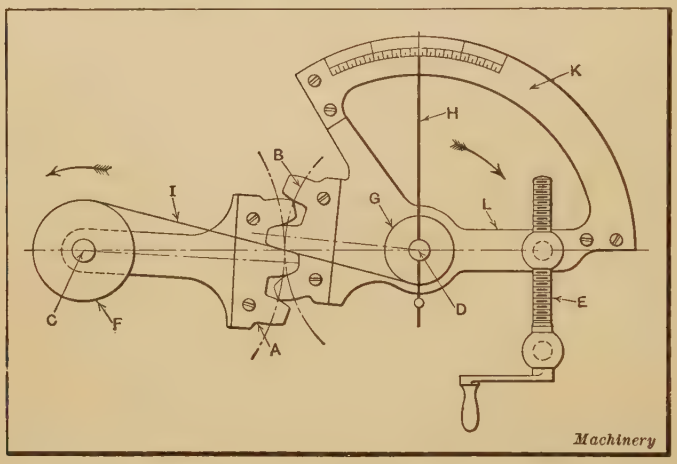


Fig. 19. MacCord Odontoscope for Testing Involute Curve of Gear Teeth

turning about the axes *C* and *D*, the distance between which is adjustable. Shaft *D* carries a graduated segment *K*, which may be slowly rotated by arm *L* and screw *E*, or any other equivalent device. Motion is thus communicated to *C*, the teeth *A* being kept in contact with *B* by a light weight or spring, not shown.

Cylindrical barrels *F* and *G* are accurately turned to the same diameter as the pitch circle from which the involute curves are struck off; *F* is fixed on the axis *C*, while *G* carries a pointer *H* that turns freely on axis *D* and is connected by a spring, not shown. The tendency is to wind up on barrel *G* the fine flexible wire *I*, which is secured to both barrels in the manner of a

cross belt. Therefore, barrels *F* and *G* turn in opposite directions with a constant velocity ratio. The velocity ratio of *C* and *D*, however, is determined by the templets *A* and *B* that will not remain in mesh unless the contour of the teeth is strictly conjugate. While turning the tangent screw in one direction or the other, it is possible to examine the action during the arc of approach or retreat of the teeth, and if the templets are correctly formed, the segment *K* and pointer *H* will move at the same rate and in the same direction, so that, if the pointer is set at zero in the graduated arc, it will remain at zero throughout the action, any movement indicating an inaccuracy in the shape of the involute curve. For actual work the sensitiveness of the involute is increased by introducing multiplying gears between barrels *F* and *G*, thus producing a greater deflection of needle *H* for a given magnitude of error, and causing minute errors to be indicated.

Testing Spur Gears for Noise under Load. — After the gears are cut and inspected for other defects, they are generally subjected to a noise test. In making this test, it is the general practice to hold the gears to be tested in some sort of fixture in which a load can be applied while the gears are running at high speed. It is also customary to have the load either approximate or exceed that which will be carried by the gear under actual working conditions. Fig. 20 shows a gear testing fixture for spur gears which embodies the features just mentioned. This consists of a base carrying three slides. The slides at the rear, which are guided by ways on the bed, are held accurately in line with each other and are gibbed to the bed. The right-hand bracket carries a dead center and the left-hand bracket, a driving center, rotated by the pulley shown. The gear to be tested is held on a mandrel and is in mesh with another gear held on a spindle that rotates in bronze bearings. The outer end of this spindle carries a disk and band brake.

In operation, the gear to be tested is located as shown, and the gear on the spindle is brought into mesh with it by the hand-lever at the front of the machine. The power is turned on slowly at first and then gradually increased. At the same

time the band is tightened on the disk to increase the power required to rotate the gear on the spindle. The operator meanwhile observes closely the noise produced. If it makes a humming sound, the gear is all right, but if it makes an intermittent noise or clash, it indicates that the teeth are unevenly spaced, eccentric with the hole, or incorrectly formed.

Testing Bevel Drive Ring Gears. — Several methods are employed for testing bevel drive ring gears for automobile transmissions. One of the most important tests is to determine within fixed limits the relation of the teeth to the back face and

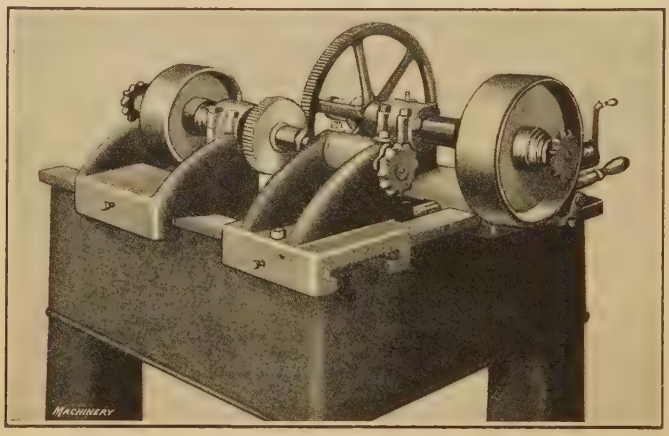


Fig. 20. Fixture for Testing Spur Gears for Noise under Load

hole. In the helical type of ring gear this is generally accomplished by what is known as a "ball test." The ring gear to be tested is fastened by the bolt holes to a carefully ground ring, which forms a part of the fixture and is free to rotate. The inspecting is done by means of a dial test indicator held in an arm, in the lower or measuring end of which is a carefully ground and lapped ball that is brought in contact with the teeth being tested. The spindle carrying the ball is kept in contact with the gear teeth by means of a stiff spring, and the ball is raised up out of contact with the teeth by a lever. The spaces between the teeth are tested in this way after the gear has been hardened, and the gear is allowed to run out about 0.003 inch.

Testing Ground Faces of Bevel Ring Gears. — In grinding the rear face of a bevel ring gear, it is the usual practice to locate the gear from the pitch line of the teeth by means of accurate balls. After the front and rear faces and hole have been ground, the gear is tested in the manner shown in Fig.

Fig. 21. Fixture used in Testing Large Bevel Ring Gears for Truth after grinding Back and Front Faces

21. The fixture here shown consists of a cast-iron base *A* to which a hardened and ground steel ring *B* is fastened. In the top face of this ring are carried steel balls on which the gear rests. The ring gear is located from the hole by a hardened and ground stud *C*, which is fastened to the cast-iron base. The test for truth is accomplished with the test indi-

cator *D* held in the bracket *E*. Bracket *E* is free to swing about the stud on which it is mounted when the clamp shown is released. The inspector, in testing for truth, rotates the gear on the balls as shown in the illustration, and at the same time watches the movement of the indicator needle to see if any inaccuracy has been caused by the grinding operation. As extreme accuracy in this part is necessary, a duplicate fixture is used in the grinding department by the operator (the one who grinds the inside face of the gear) to determine if the

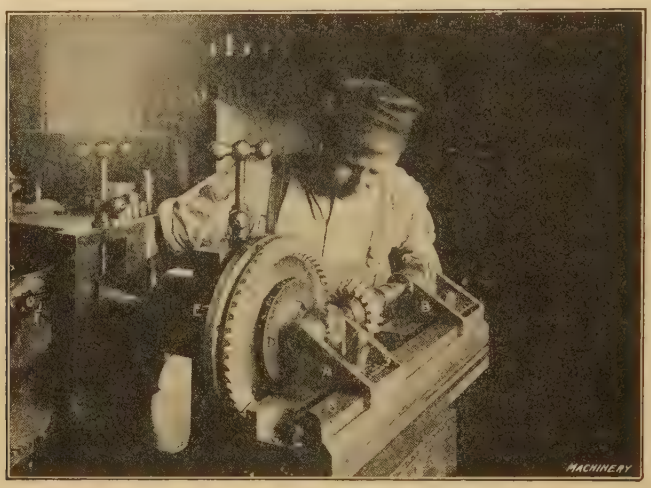


Fig. 22. Running Test for Noise on Bevel Ring Gears and Pinion, accomplished by Hand

final grinding operation is correct before the gears leave the grinding department.

Testing Bevel Gears for Noise. — Bevel gears are subjected to a noise test in a similar manner to that described in connection with transmission gears. Several devices have been developed for the purpose, one of which is shown in Fig. 22. This is made from a discarded Lincoln type milling machine. The testing fixture comprises two brackets held on the table, and a special holder on the spindle for the ring gear. The brackets *A* and *B*, which carry centers for supporting the pinion arbor, are held to the special table *C* by T-bolts and nuts. The

bracket *A* is provided with a wing-nut, so that it can be easily removed to insert the work. The ring gear is held in a manner similar to that employed in the Gleason bevel gear generator, being located from the front inside face by a shoulder plate *D*, to which the gear is bolted. Spring pins located in the special faceplate *E* are also used to support the rim of the gear. The machine is provided with a special hardened and ground spindle on which the ring gear fixture is retained. The spindle is hollow and a pull-rod passing through it is used to clamp the gear and shoulder plate *D* up against the fixture. To the rear end of the spindle is attached the handle *F*, which is used to

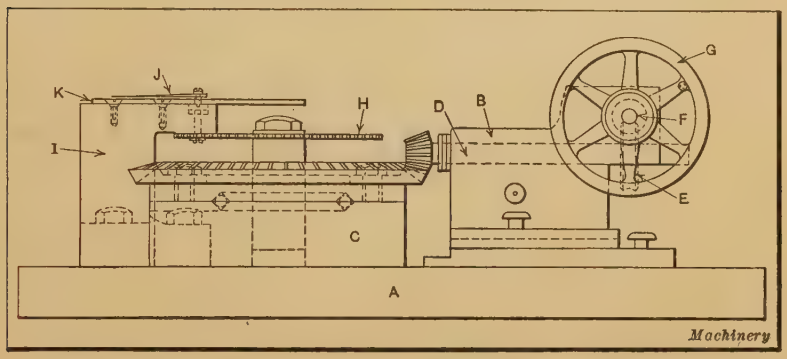


Fig. 23. Special Fixture for Testing Running Action of Bevel Ring Gear and Pinion

rotate the ring gear that meshes with the pinion held on the arbor. The operator brings the ring gear and its mating pinion into mesh, and then rotates the handle *F* slowly, listening carefully to find out at which points of the rotation noise is produced or where the teeth bear hard. In addition to this, the ring gear and mating pinion are given a noise test under load, while being rotated at a high speed.

Testing Running Action of Bevel Gears. — A bevel ring gear and pinion must be accurately mounted to give satisfactory results, and in order to determine whether the gear will run correctly or not when mounted, it is advisable in most cases to test the gear under actual working conditions in a special fixture that has been designed for the purpose, and so

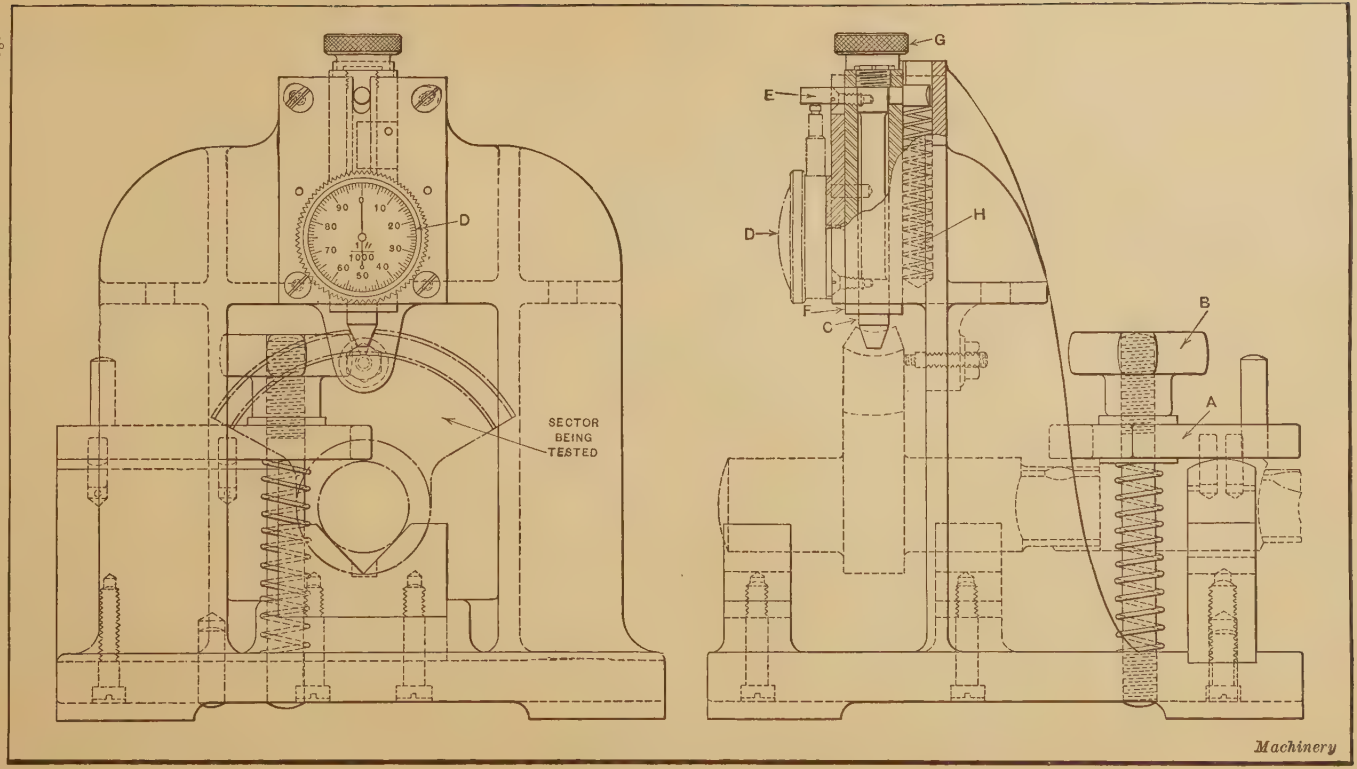


Fig. 24. Fixture for Testing Eccentricity of Steering Gear Sector

arranged that any errors in the gear are magnified. A simple testing device which gives satisfactory results is shown in Fig. 23, and consists of a base *A* upon which is mounted an adjustable bracket *B* that carries the bevel pinion, and a bracket *C* that carries the ring gear. The pinion shaft *D* is driven by a worm-wheel *E*, which, in turn, receives power from a worm held on shaft *F*, the latter being rotated by handwheel *G*. The bevel ring gear is mounted so that it is free to be rotated by the pinion. Located on the spindle to which the ring gear is attached is a fine-pitch spur gear *H* which meshes with a pinion held in a bracket *I*. The ratio between this spur gear and pinion is 10 to 1. Located on the pinion shaft is a pointer *J* which rotates around the graduated dial *K*, the latter being attached directly to the bracket *I*.

In operation, the pinion and bevel ring gear are carefully mounted and then handwheel *G* is rotated at a uniform speed. If the bevel pinion and ring gear are properly cut and in correct mesh, the indicator *J* will travel over the dial *K* with a steady, uniform motion. On the other hand, if the meshing is incorrect, the pointer will move over the dial with a jerky, irregular motion. The block *B* carrying the horizontal pinion shaft is adjustable so that the gears can be made to mesh incorrectly in order to study the effect of this action. The fixture is so designed, however, that there is one correct position that cannot be varied more than 0.001 inch.

Testing Fixture for Steering Worm Sectors. — Fig. 24 shows a testing fixture which is used for determining the amount of eccentricity of a steering worm sector, as used on the Cadillac motor car. This particular steering worm sector is made eccentric so that, by adjusting an eccentric bushing, any wobble can be taken up in the steering sector until it has been worn down to an "equal radius." The teeth on this sector are not concentric with the shank, and as they wear more in the center than at either end, this allowance for adjustment is necessary. In order to check the amount of eccentricity on this sector, a special testing fixture has been devised as shown in Fig. 24. Here the steering worm sector is shown, by heavy dotted lines,

mounted in two V-blocks and held just tight enough to prevent any lost motion, by means of a toe-clamp *A* and a nut *B*. The sector is then swung around past the rack tooth *C*, which meshes with the teeth in the sector. The amount that the center of the worm is eccentric with the two extreme ends of the sector is then determined accurately by means of the dial

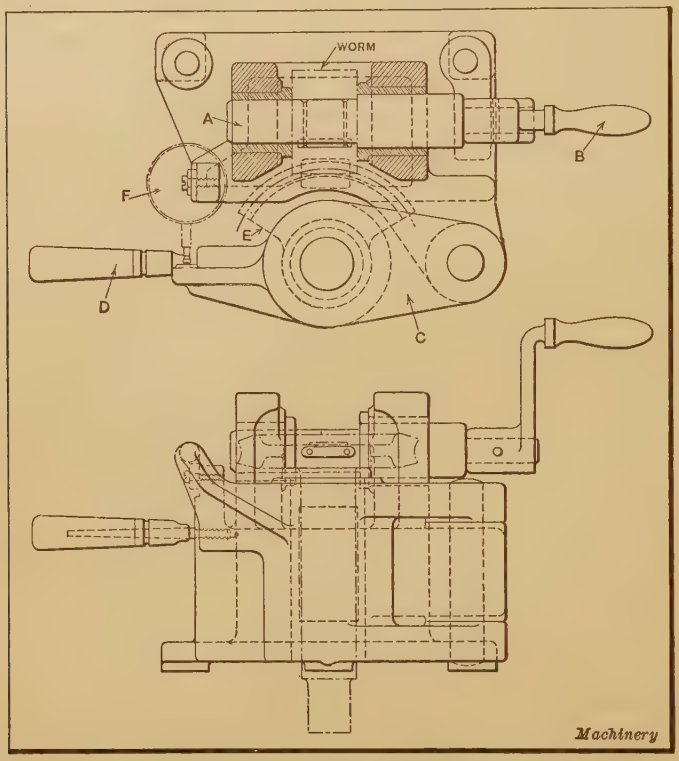


Fig. 25. Fixture for Testing Center Distance of Steering Gear Sector and Worm

test indicator *D*, which is acted upon by the pin *E* held in the slide *F*. This slide is moved up against the tension of spring *H* by pulling on button *G*.

Fixture for Testing Center Distance of Steering Sector and Worm. — After the amount of eccentricity of the worm sector has been tested in the fixture shown in Fig. 24, the next step

is to test the center distance of the worm in connection with the sector, working the latter on the high point, as indicated in Fig. 25. The worm is held on a shaft *A* provided with a key for driving it, this shaft being rotated by handle *B*. The sector is held in a swinging member or arm *C* operated by handle *D*. The worm is placed on shaft *A*, sector *E* is then placed in swinging arm *C*, and the latter is swung in until the sector meshes properly with the worm. From time to time, this fixture is tested and set by a master sector and worm and then a reading is taken on the dial test indicator *F*. When the work being tested is put in this fixture, the needle must indicate within ±0.001 inch of the zero point registered by the master. In order to see that the worm is not eccentric, it is rotated by means of handle *B*, and as the swinging arm *C* is only held in by means of the hand, the eccentric movement of the sector is easily noticed, if the arm is forced back by the rotation of the worm. This gives an indicating reading on the dial test indicator, and the amount of eccentricity may also be determined in the same fixture.

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